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PENNSYLVANIA GEOLOGY

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THE PENNSYLVANIA GEOLOGICAL SURVEY VOL. 20/

COMMONWEALTH OF PENNSYLVANIA
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ON THE COVER: A cluster of small potholes cut into diabase at Conewago Falls, Susquehanna River, Lancaster County, by sand and silt grains carried in rapidly moving water (see article on page 2). Photograph by W. D. Sevon.

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Editors, Christine M. Dodge and Donald M. Hoskins

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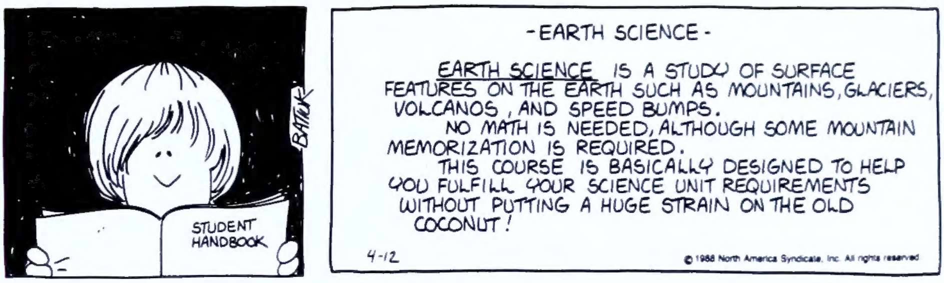
STUDENT HANDBOOK
BATIUK
- EARTH SCIENCE -
EARTH SCIENCE IS A STUDY OF SURFACE FEATURES ON THE EARTH SUCH AS MOUNTAINS, GLACIERS, VOLCANOS, AND SPEED BUMPS.
NO MATH IS NEEDED, ALTHOUGH SOME MOUNTAIN MEMORIZATION IS REQUIRED.
THIS COURSE IS BASICALLY DESIGNED TO HELP YOU FULFILL YOUR SCIENCE UNIT REQUIREMENTS WITHOUT PUTTING A HUGE STRAIN ON THE OLD COCONUT!
4-12
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From "Funky Winkerbean," April 12, 1988. Reprinted with special permission of NAS, Inc.

Earth Science in the "Funny Pages"

The "funny pages" of our local newspaper are an odd place to learn about public perceptions of earth science. In the cartoon, earth science is described as studying natural landforms, which we do, and also unnatural landforms, which we also do (if one can consider human-caused landslides as large "speed bumps").

The truth of the earth sciences (which includes geology) is that natural features are a delight to study. Nature, while frequently destructive, is also constructive. Nature produces, among other features, sculptures of great beauty and wonderment as may be seen in the Susquehanna River near Harrisburg (see article herein). Studying such natural features may appear not to put "a huge strain on the old coconut." In truth, interpretation of the origin, sequence of development, age, and future of these sculptured rocks requires extraordinary knowledge, perception, and ability to reason, in addition to understanding the complex physics (and math) of fluid flow with its included erosive particles. The lack of apparent "strain" is the result of the great personal satisfaction our scientist achieves in understanding nature's beauty. Enjoyable labor is unlaborious.

There is a serious danger if public perception of earth science remains that it is an "easy" science. Intelligent young people, who will be needed in future years to solve and explain the many earth science-related environmental problems that face our ever-growing population, will avoid earth science if they feel it is an "easy" science. We should use the enjoyable labor of earth science to attract future scientists, but we need to let them know of the necessary effort they must exert to achieve the personal satisfaction they will receive. Just as the sculptor labors to create a work of art so does the geologist labor to explain nature's art (and nature's "speed bumps").

Donald M. Hoskins

Donald M. Hoskins
State Geologist

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EXOTICALLY SCULPTURED DIABASE

by W. D. Sevon
Pennsylvania Geological Survey

Introduction

A variety of intricate and interrelated forms have been eroded into resistant Jurassic diabase at Conewago Falls on the Susquehanna River in northwestern Lancaster County, Pennsylvania (Figure 1). The

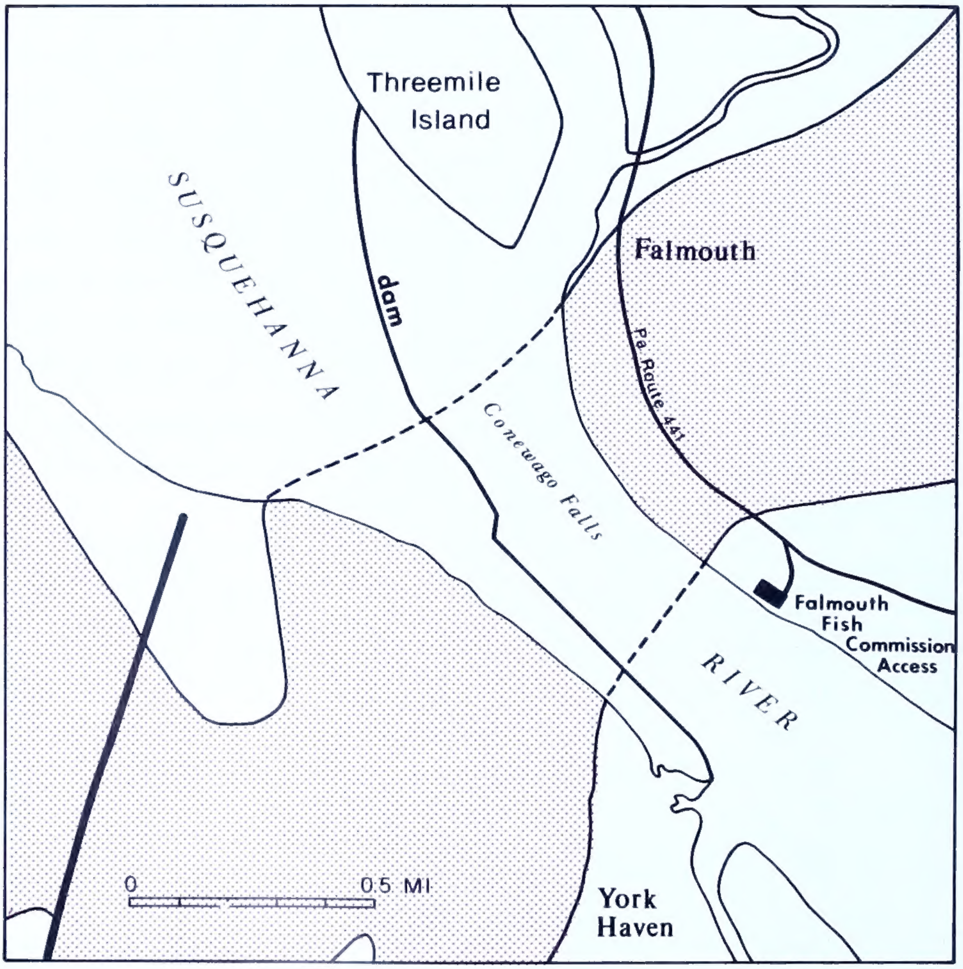

Figure 1. Location and geologic map for Conewago Falls. The colored area represents Jurassic diabase. The rock north of the diabase is the Triassic Gettysburg Formation, and the rock south of the diabase is the Triassic New Oxford Formation.

diabase occurs in a sill that crosses the Susquehanna River immediately south of Threemile Island. The resistant nature of the diabase has caused constriction of the Susquehanna River to about one third of its immediate upstream size, and the river flows through a gorge about 2,000 feet wide. The diabase is lithologically homogeneous and is broken by parting planes that have a low north dip (<10 degrees) and various joint planes that are oriented more or less northeast-southwest and northwest-southeast. The parting planes have a spacing generally between 2 and 4 feet, and the spacing of the joints is quite variable. The diabase is bounded on the top and bottom by hornfels, which represents Triassic sediment baked and altered during intrusion of the diabase sill.

Two principal forms of fluvially sculptured diabase occur in the riverbed: potholes and asymmetric ripples. These principal forms are accompanied by various pits and channels. The two principal forms occur in different parts of the riverbed; the asymmetric ripples occur in the center riverbed and the potholes occur on the riverbed sides. Both are the product of erosion by the river.

Asymmetric Ripples

The asymmetric ripples (Figure 2) occur in the center riverbed where the flow velocity is highest and turbulence least. Sand grains carried by high-velocity flow impinged upon the upstream-dipping diabase surfaces and eroded the diabase by abrasion. Fluid dynamics created flow patterns that caused the sand abrasion to form ripples. Ideally, the erosion created a sequence of ripples in which

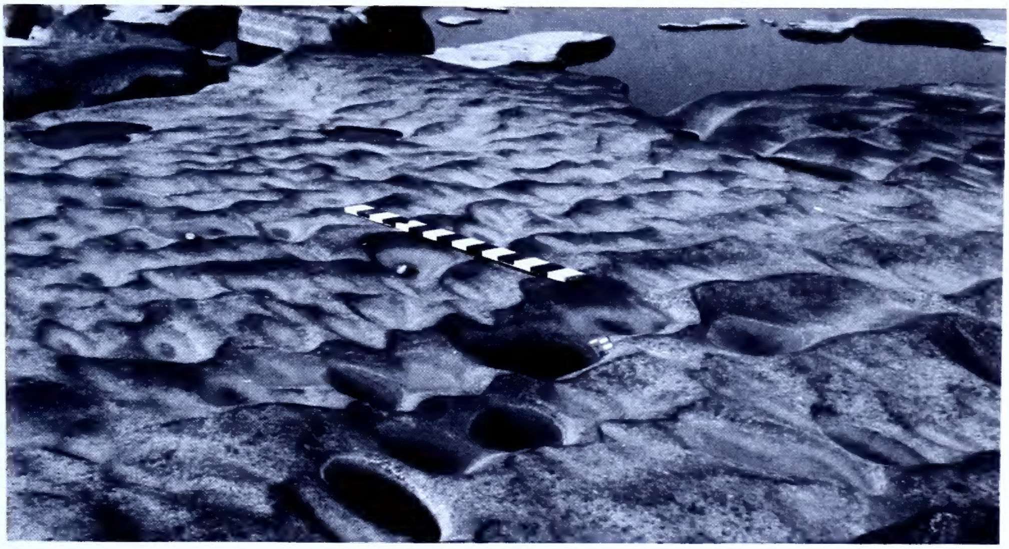

Figure 2. Asymmetric ripples cut into diabase. Upstream is to the left. Scale intervals are 4 inches.

the amplitude and wavelength of subsequent ripples increased downstream from the point of initial impingement. In reality, the attitude and position of the rock at the point of impingement often caused variations on the ideal. As a result, forms created in the center riverbed vary from those shown in Figure 2 to the extreme shown in Figure 3 in which the crests of the ripples, the rounded high points, are obscured by both the rounding of the crests and the size of adjacent potholes. A more common modification of the ripple form is the development of flow-parallel channels (Figure 4). These channels formed because the changing shape of the ripple crests reoriented flow and caused flow-parallel abrasion.

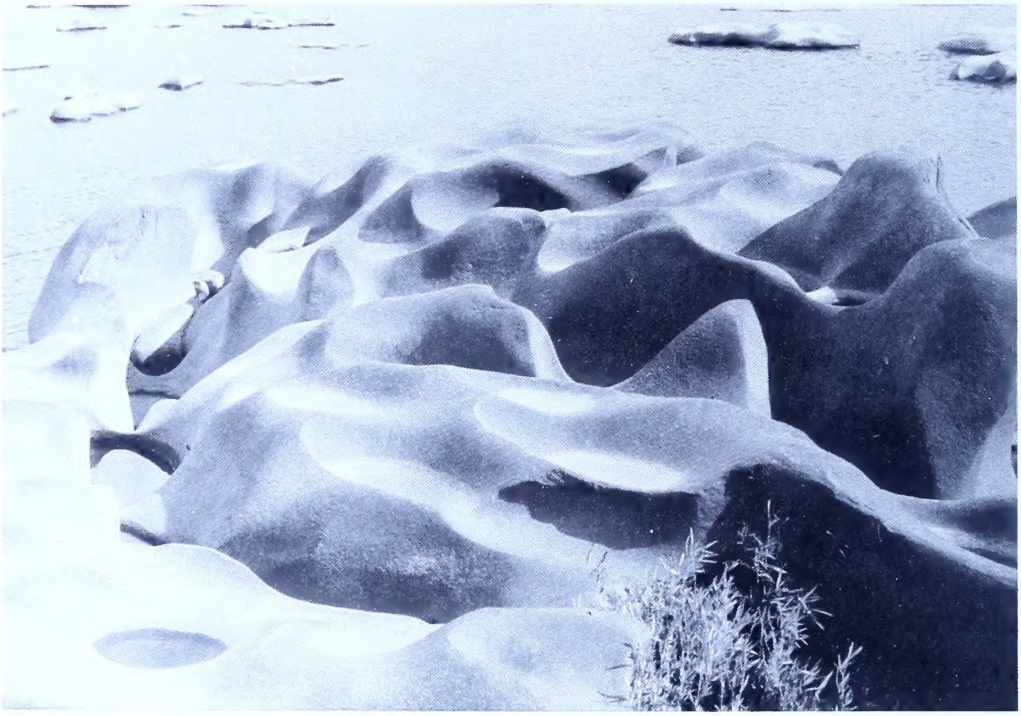

Figure 3. Extreme sculpturing of diabase has almost obliterated ripples. Upstream is to the left.

Potholes

The riverbed sides show the contrasting results of slightly slower flow velocity and maximum turbulence. No ripples have been formed in the riverbed sides. Instead, abrasive erosion has been concentrated at the points of rock weakness—the joints. Abrasion in the riverbed sides has eroded mainly potholes at points of intersection of joints (Figure 5) and some flow-parallel and flow-normal channels (Figure 6).

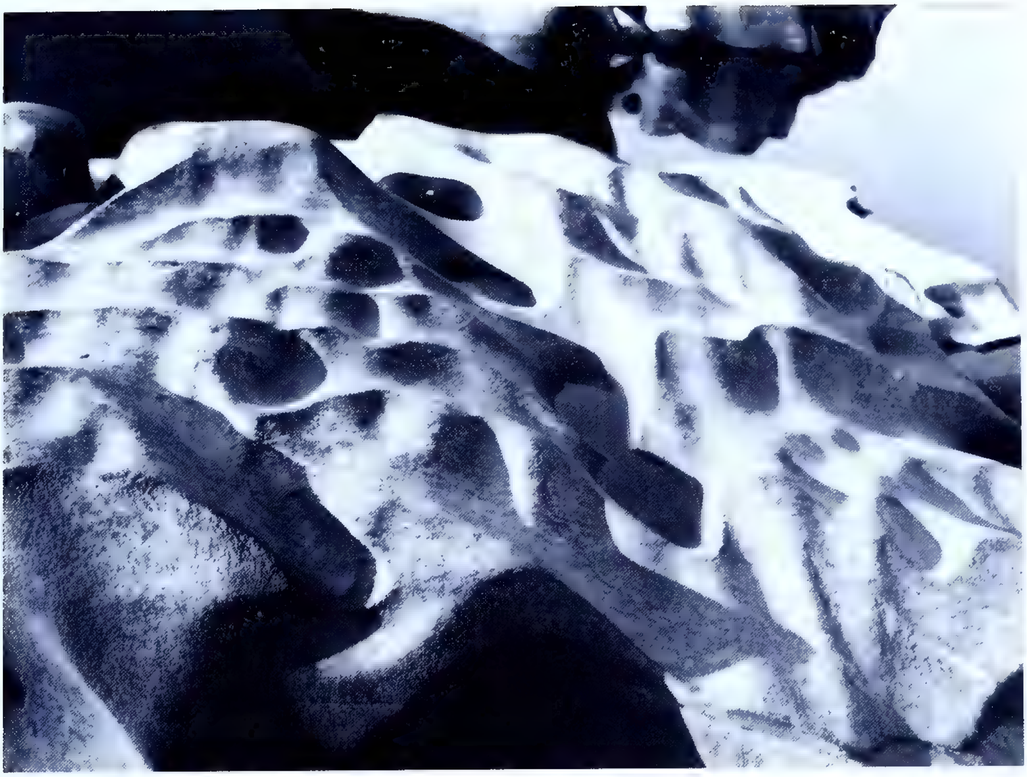

Figure 4. Flow-parallel channel being cut into diabase. Upstream is at the top. Scale intervals are 4 inches.

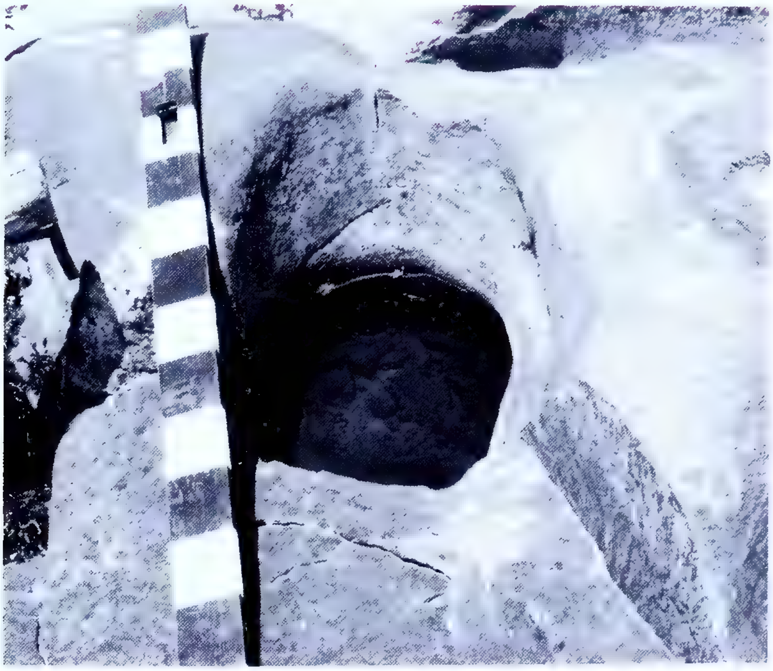

Figure 5. Pothole eroded in diabase at location of joints and joint intersections. Scale intervals are 4 inches.

The potholes range in size from about 1 inch in diameter and 12 inches deep to about 5 feet in diameter and 8 feet deep. Most potholes are between 1 and 2 feet in diameter and are generally only 3 to 4 feet deep. The depth of the potholes is apparently controlled by the thickness of the diabase layer between partings.

The potholes have presumably been eroded by hydraulic vortices (Figure 7) created by turbulence during high-velocity flow. A hydraulic vortex creates a boil on the surface of the water and draws water and sediment into its center at the point of impingement with rock. Sand entrained in the swirling motion on the outer part of the vortex abrades the rock as it is carried to the bottom of a developing pothole, where the eroded detritus is carried upward through the center of the vortex. Once a position of vortex motion is established it apparently persists as long as the conditions of flow are favorable, thus accounting for the depth of some potholes. The channels result from abrasion caused by concentrated flow other than hydraulic vortices. The combination of potholes, channels, joint planes, and parting planes weakened the layered diabase and aided plucking of large and small pieces of rock to further erode and lower the riverbed.

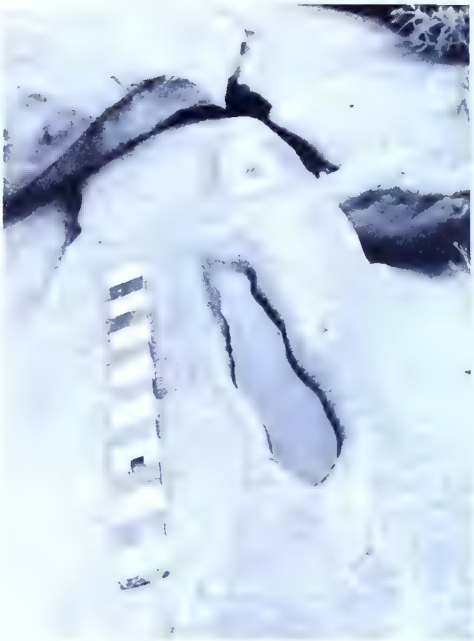

Figure 6. Flow-normal channel cut in diabase. Upstream is to the right. Scale intervals are 4 inches.

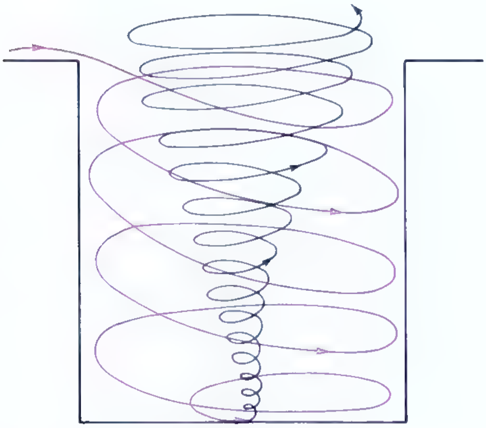

Figure 7. Flow patterns of a hydraulic vortex in a pothole. Outer flow (color) carries sand into the pothole and abrades the sides. Inner flow removes material. Model from Baker (1973) and Gray (1988).

Discussion

None of the sculptured forms at Conewago Falls appear to be in the process of continuing development at the present time. Although this could be the result of reduced flow dynamics caused by the low dam to the north which impounds water for the York Haven power station, it is more probable that the real causes are reduced long-term, high-velocity flow and the smaller grain size in the sediment load. During Pleistocene deglaciation the Susquehanna River presumably had high-velocity flow for long periods of time and carried considerable quantities of sand. It was during this time that the sculptured forms at Conewago Falls were eroded. Since the end of this period of abrasive erosion, nearly 20,000 years ago, only short terms of high-velocity flow have occurred, and the sediment load has been mainly silt and clay. Consequently, erosion at Conewago Falls has taken place mainly by the plucking of individual pieces of rock.

The sculptured forms at Conewago Falls are easily reached by parking in the Falmouth Fish Commission Access on the east side of the river and walking upstream along the river's edge. Many of the good potholes can be viewed when the river stage is around 4 feet at Harrisburg, but the asymmetric ripples in the center of the riverbed can be seen only when the river stage at Harrisburg is 3.5 feet or lower. The ripples occur north of the third power line north of the parking lot. Potholes occur all along the east bank. A trail paralleling the river in the woods on the east bank simplifies returning to the parking lot.

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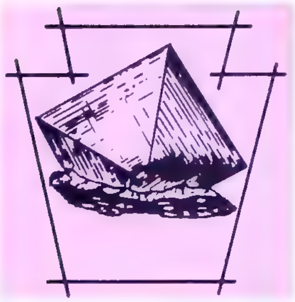
Pennsylvania Academy of Science To Meet

The 65th Annual Meeting of the Pennsylvania Academy of Science will be held at Mt. Airy Lodge, Mt. Pocono, Pennsylvania, on April 7–9, 1989. For information contact the Convention Chairman, Dr. Sherman Hendrix, Department of Biology, Gettysburg College, Gettysburg, PA 17325.



EARTH SCIENCE TEACHERS' CORNER

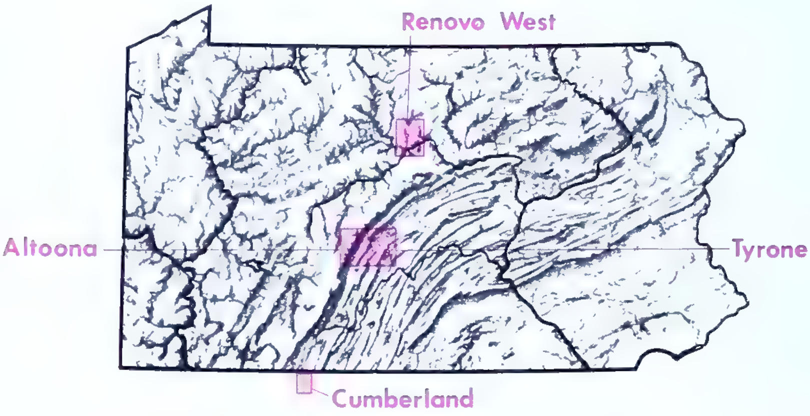
by Sandra Blust
Pennsylvania Geological Survey

Physiographic Features of the United States Illustrated in USGS Map Set

There is available to teachers of physiography a set of topographic maps published by the U.S. Geological Survey (USGS) illustrating the great diversity of topographic features found in the United States, including features best illustrated in Pennsylvania.

Included in the set are three 15-minute topographic maps from Pennsylvania: the Renovo West quadrangle represents the Appalachian Plateaus province, the Tyrone quadrangle represents the Valley and Ridge province, and the Altoona quadrangle represents parts of both provinces. Also included in the set is the Cumberland 7.5-minute quadrangle, which covers portions of Maryland, Pennsylvania, and West Virginia and represents the Valley and Ridge province and part of the Appalachian Plateaus province. Some physiographic features evident on these maps are dissected plateaus, hogbacks, stream piracy, structurally controlled dissected terraces, synclinal valleys and synclinal mountains, anticlinal valleys and anticlines, slip-off slopes, undercut slopes, and wind and water gaps.

These maps are described and located in *Index to a Set of One Hundred Topographic Maps*. One side of the index contains a map,



Physical Divisions of the United States, which shows the boundaries of the 75 physiographic provinces and sections and the general locations of the 100 quadrangle maps. On the other side of the index, the physiographic features shown on each topographic map are listed and summarized. One list shows the features arranged alphabetically by state and quadrangle. In a second list, the features are arranged by physiographic category, and the quadrangles are identified.

Within the set of 100 maps is a smaller group of 25 maps also available as a set. The set of 25 maps contains a variety of physiographic features that represent most of the major physical divisions of the United States and is available for those interested in a limited study. The Renovo West quadrangle is the only map from Pennsylvania included in the 25-map set.

The index to the topographic maps is available free from the USGS by writing Map Distribution Section, U.S. Geological Survey, Box 25286, Federal Center, Denver, CO 80225, or by telephoning the National Cartographic Information Center Office at 1-800-USA-MAPS. The set of 100 maps is priced at $200.00, and the smaller set of 25 maps at $50.00. Prepayment is required and must accompany the order.

New Index of Topographic Maps of Pennsylvania Now Available

The topographic maps covering Pennsylvania and available from the U.S. Geological Survey (USGS) through its various distribution services are now described in a new catalog and index published in booklet form, replacing the former single-sheet index.

All cartographic products produced by the USGS relating to Pennsylvania—topographic maps, planimetric maps, satellite images, land use maps, orthophotoquads, and radar images—are contained in one index. The new catalog also includes United States maps, county maps, national park maps, National Atlas maps, world maps, and special maps that include parts of Pennsylvania.

The catalog contains forms for ordering topographic and other maps from the USGS. The catalog also contains lists of private map dealers in Pennsylvania and libraries in Pennsylvania that have maps for reference.

Single copies of the index and catalog are available from the Pennsylvania Geological Survey, NCIC Affiliate Office, P. O. Box 2357, Harrisburg, PA 17120, telephone 717-783-8077. Copies are also available from the U.S. Geological Survey, Map Distribution, Box 25286, Denver, CO 80225.

Abundant Fossils at New Allegheny County Locality

by John A. Harper
Pennsylvania Geological Survey

Fossil collectors in Pennsylvania will welcome a new locality that has not been described previously and has not received attention from the local fossil-collecting community. This Allegheny County site was called to my attention by Pittsburgh area fossil collectors Dan Hamilton and Frank Stingone. The locality is good, both in terms of fossil content and accessibility, and will be good for large groups providing that necessary cautions are taken.

The locality consists of a roadcut with outcrops on both sides of Pa. Route 28, the Allegheny Valley Expressway, between the Cheswick and Creighton exits, New Kensington West 7.5-minute quadrangle, east-central section (Figure 1). The cut goes deep into the hillside about 0.3 mile south of the Creighton exit. Those interested in visiting this locality should be aware that Pa. Route 28 is a high-speed, four-lane divided highway similar to an interstate highway.

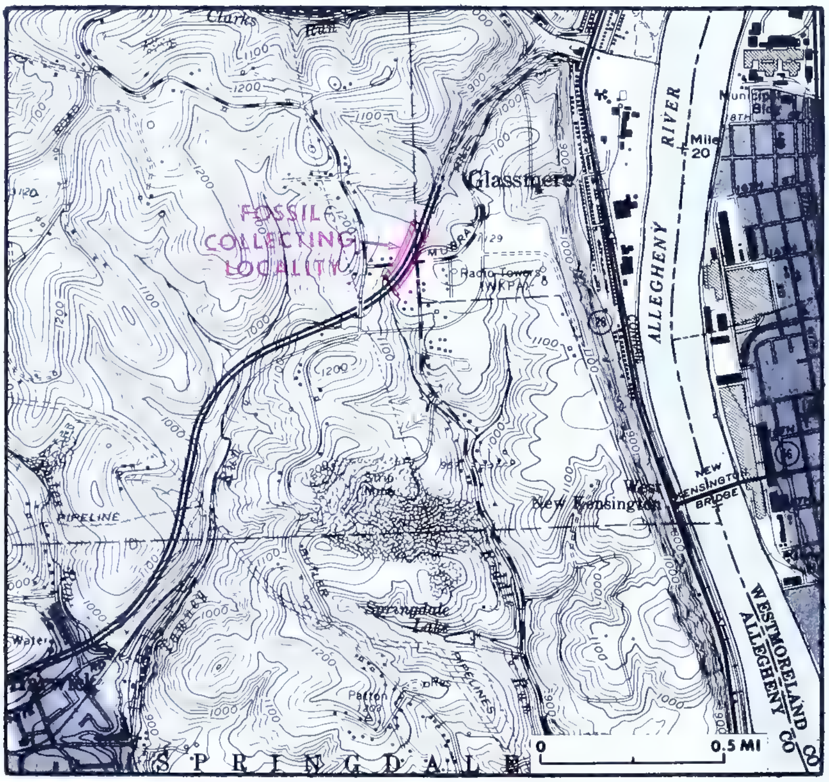


Figure 1. Location of the Allegheny County fossil-collecting site along Pa. Route 28, the Allegheny Valley Expressway near Cheswick.

EXTREME CAUTION should be exercised in parking and walking on the road, and especially in crossing the highway. Parking is available on the wide shoulders, and cars should be pulled as far off the side of the road as possible.

This roadcut contains exposures of the middle portion of the Conemaugh Group from the Saltsburg member of the Glenshaw Formation at the bottom to the Morgantown member of the Casselman Formation at the top (Figure 2). The Ames, which consists of a tripartite unit of calcareous shales and limestones, stands out from the surrounding shales and claystones because of its inherent resistance to erosion. Erosion of the outcrop, especially of the underlying Pittsburgh "red beds," has taken its toll, and large blocks of the undercut Ames periodically break off and lie within or below the talus slope beneath the outcrop. The three basic layers of the Ames include about 0.5 to 3 inches (10 to 75 mm) of hard calcareous shale at the base, overlain by 18 to 36 inches (0.5 to 0.9 m) of very hard, argillaceous limestone, which is capped by about 10 inches (25 cm) of relatively fissile, calcareous shale.

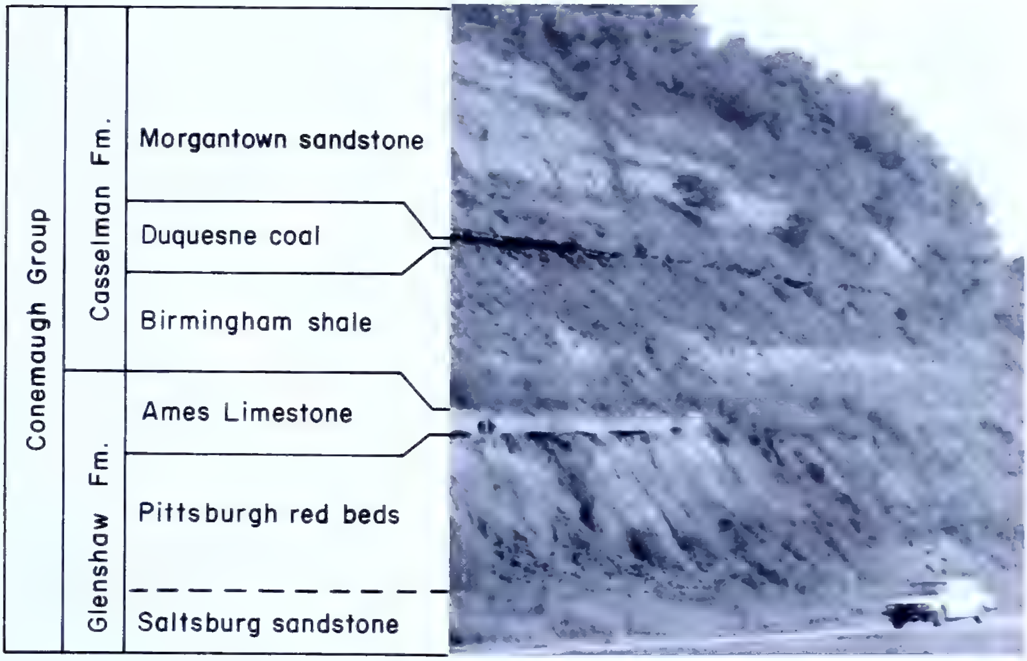


Figure 2. Outcrop along Pa. Route 28 near Cheswick. The middle portion of the Conemaugh Group is exposed, from the Saltsburg sandstone at the base to the Morgantown sandstone at the top. The Ames Limestone is very fossiliferous at this locality. Some plant fossils are associated with the Duquesne coal.

The lower calcareous shale is phosphatic and contains a hash of diverse faunal elements. Most of the fossils in this unit have undergone some crushing. The majority of complete or nearly complete fossils are of molluscs, particularly the gastropod *Glabrocingulum (Glabrocingulum) beedei* Mark, a species named from the Ames Limestone of eastern Ohio. This gastropod occurs in such great numbers in some places that it is hard to distinguish separate individuals. Other gastropods, bivalves, cephalopods, and brachiopods are also common in this layer. The phosphatic material consists mostly of small nodules, and calcium carbonate shells are commonly replaced by phosphate minerals. Although phosphatic nodules are common in the basal layers of the Ames, the rock at this locality is peculiar in the amount of phosphatic material present. Most of the molluscan fossils, which had original aragonitic shell layers, have been completely replaced by phosphatic minerals. This replacement phenomenon has occurred with perfect duplication of the finest details of shell sculpture, and some of the fossils that were seen or collected even had what may have been remnants of original color markings.

The thick middle section of limestone, the Ames Limestone proper, contains a diverse fauna of brachiopods, corals, and crinoids. Also observed were some interesting burrow structures containing shell hash, disturbed bedding, and, in at least one case, rip-up clasts of the lower molluscan-rich layer. There are some corals scattered throughout the limestone, but for the most part they occur at discrete

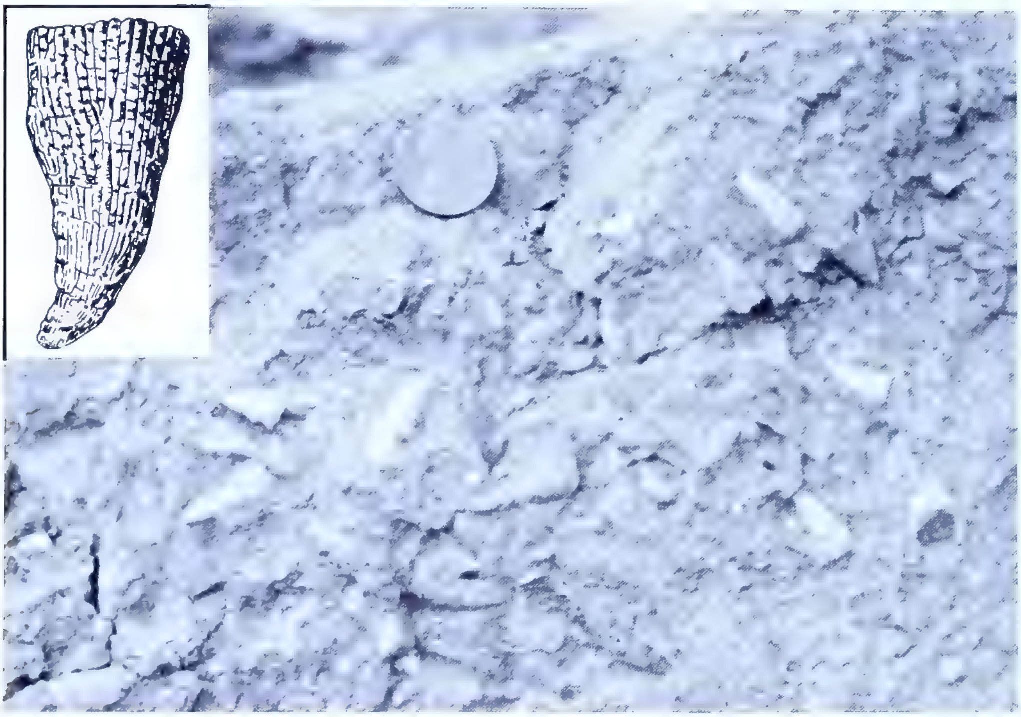


Figure 3. Scattered specimens of the horn coral *Stereostylus* on a bedding plane in the Ames Limestone. The inset illustrates a typical coral for comparison, x1.

horizons (Figure 3), often in association with phosphatic nodules. Some of the crinoid material observed on the surface of the rock appeared to represent nearly complete small specimens, but they were nearly impossible to remove from the enclosing rock. The buff-colored rock, which is typical of the Ames in western Pennsylvania, is generally much more difficult to break up than the associated shales. A small sledge hammer and a good chisel will be somewhat useful for the ambitious collector and may prove to be necessary in order to remove anything of interest. Many of the float blocks of limestone are too big to break with anything less than a large sledge hammer.

The upper shale section is typically rich in corals and brachiopods, particularly *Crurithyris planoconvexa* (Shumard), *Composita subtilita* (Hall), and *Composita ovata* Mather. *Crurithyris* often occurs in such abundance that the shells may be mistaken for small pebbles in the rock (Figure 4). The rock itself consists of easily broken, buff-colored, slightly calcareous shales or other mudrocks. Thin lenses of limestone similar to the main bed occur in a few places. The fossil content decreases upward. This shaly portion of the Ames sequence commonly remains attached to the underlying limestone when the rock ledge breaks off and falls from the outcrop. As such, it typically contains the fossils that are easiest to collect.

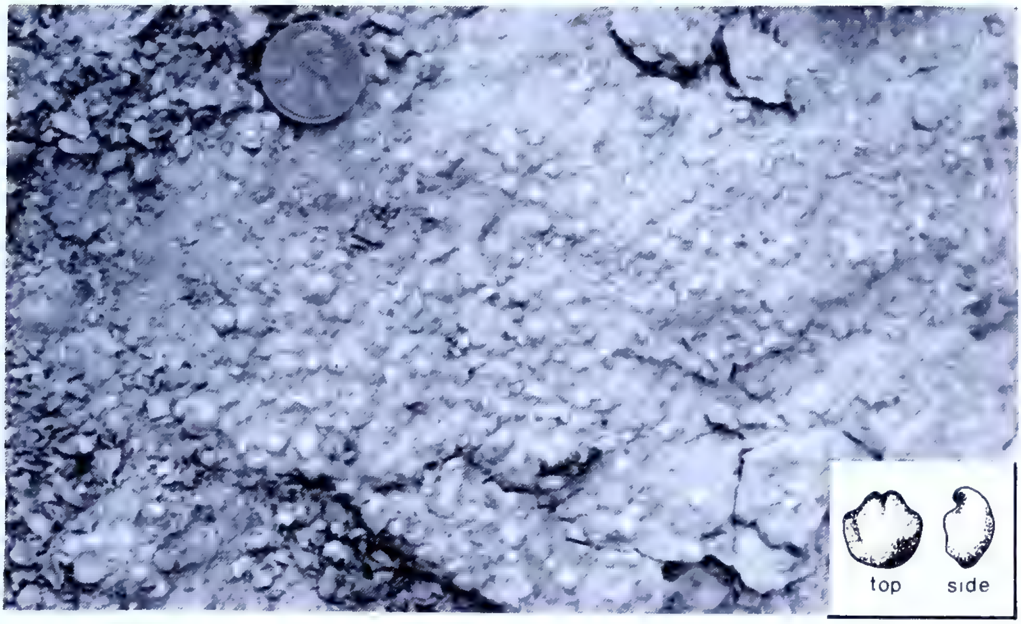


Figure 4. The brachiopod *Crurithyris* is so abundant in some portions of the Ames Limestone that it may be mistaken for small pebbles. The inset illustrates two views of the brachiopod for comparison, x1.

There is an interesting fossil at this locality that bears mentioning here. In Table 1, an item called "aptychus" is listed under the cephalopods. An aptychus is a bivalve-like fossil that bears little resemblance to cephalopods as a whole. Aptychi occur mainly in association with Mesozoic ammonite fossils; only a handful have

Table 1. *Fossils Observed or Collected from the Allegheny County Locality*

CORALS
Stereostylus ssp.

BRACHIOPODS
Derbyia crassa (Meek and Hayden)
Derbyia parvicostata Sturgeon and Hoare
Schuchertella sp. cf. *S. pratteni* (McChesney)
Neochonetes granulifer (Owen)
Hystriculina wabashensis (Norwood and Pratten)
Juresania nebrascensis (Owen)
Antiquatonia portlockiana (Norwood and Pratten)
Linoproductus prattenianus (Norwood and Pratten)
Wellerella osagensis (Swallow)
Hustedia mormoni (Marcou)
Composita ovata Mather
Composita subtilita (Hall)
Crurithyris planoconvexa (Shumard)
Neospirifer latus Dunbar and Condra
Neospirifer dunbari King

TRILOBITES
Ditomopyge decurtata Gheyselinck

POLYPLACOPHORANS (CHITONS)
Pterochiton carbonarius (Stevens)

GASTROPODS
Euphemites sp.
Bellerophon (Bellerophon) sp.
Pharkidonotus percarinatus (Conrad)
Retispira kansasensis (Shumard)
Knightites (Cymatospira) montfortianus (Norwood and Pratten)
Amphiscapha sp.
Glabrocingulum (Glabrocingulum) beedei (Mark)
Shansiella broadheadi (White)
Phymatopleura intertexta (Meek and Worthen)

GASTROPODS *(continued)*
Phymatopleura nodosa (Girty)
Pseudozygopleura (Pseudozygopleura) scitula (Meek and Worthen)
Strobeus paludinaeformis (Hall)
Strobeus primogenius (Conrad)
Strobeus brevis (White)

CEPHALOPODS (mostly fragments)
Pseudorthoceras knoxense (McChesney)
Mooreoceras sp. cf. *M. normale* Miller, Dunbar, and Condra
Tainoceras? sp.
Domatoceras? sp.
Aptychus

BIVALVES
Nuculopsis girtyi Schenck
Nuculopsis croneisi Schenck
Phestia bellistriata
Parallelodon obsoletus (Meek)
Parallelodon carbonarius (Cox)
Septimyalina sp. cf. *S. perattenuata* (Meek and Hayden)
Aviculopecten carboniferous (Stevens)
Pseudomonotis? sp.
Schizodus wheeleri (Swallow)
Astartella concentrica (Conrad)
Edmondia? sp.

CRINOIDS
Assorted columnals and calyx plates

VERTEBRATES
Petalodus ohioensis Safford
Cladodus occidentalis Leidy
Helodus? sp.
Miscellaneous bone and teeth fragments

TRACE FOSSILS
Conostichus broadheadi Lesquereux
Tremichnus cysticus Brett
Miscellaneous horizontal and vertical burrows

been described from Paleozoic rocks around the world. There have been only two descriptions of aptychi from Late Paleozoic rocks in North America (Thompson and others, 1980; Kues, 1983). They are genuinely rare items, and their function is still in question. Paleontologists are still divided as to whether they are calcified cephalopod jaws or operculae, kinds of trap doors used to close the animals within their shells. The overwhelming evidence from ammonites indicates that they were probably lower jaws (Morton, 1981), but aptychi or aptychus-like fossils found in place in some Silurian straight-shelled nautiloids can only reasonably be interpreted as operculae (Holland and others, 1978). It may eventually be determined that this conflict is the result of related structures having different functions in separate cephalopod lineages. This is the first reported occurrence of aptychi from the Pennsylvanian of the Appalachian basin, and a formal notation and description have been prepared (Harper, 1989).

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NEW STAFF MEMBER

Connie A. Zimmerman

Connie Zimmerman joined the Editing Section of the Survey in November 1988. A native of Harrisburg, Connie graduated from Middletown High School in 1976 and received an Associate degree in Liberal Arts from Harrisburg Area Community College in 1978. In her position as Clerk Typist, Connie does the word processing and typesetting necessary to prepare reports for publication.

Connie has been a state employee for over eight years. She started as a Clerk in the Department of Labor and Industry, handling injury reports for the Bureau of Workers' Compensation. After four years, she took a position as Clerk Typist in the Bureau of Employer Tax Operations. In June 1988, Connie transferred to the Department of Environmental Resources, where she processed paperwork for members of the Pennsylvania Conservation Corps prior to being promoted to her position at the Survey.

The Hazards of Field Work
or
"Don't Let the Little Beasties Get Under Your Skin!"

During the early 1970's, Tom Berg was mapping in the Pocono Mountains—usually a delightful place to do field work. Tom, like most field geologists, knew to watch out for the usual hazards of mapping in the deep woods away from civilization. Rattlesnakes, copperheads, wood ticks, poison ivy, bears, and mosquitoes are all "old hat" for most seasoned field geologists. But a new problem was encountered in the Poconos that year. The gypsy moths had attacked the forest with a vengeance. By mid-July, the terrain looked like mid-November. Not a leaf was left on a tree. The gypsy caterpillars had finished off all of the deciduous trees and had attacked the hemlocks, mountain laurel, and ferns.

Tom's days in the field were a continuous encounter with literally millions of caterpillars. They were everywhere. Berg's *FIRST LAW OF FIELD WORK* was: "Under every rock there's a critter." But this was too much! Driving on the back roads, he heard continual popping and crunching of caterpillars beneath the tires. There was a sound like a light rain, caused by the perpetual fall of caterpillar droppings hitting the forest floor. Worst of all, every evening upon returning to the field headquarters, Tom would discover squashed caterpillars everywhere—under his belt, in his socks, around his collar, in his hair, in the field notes, and in between the aerial photos and maps.

One of the most fascinating phenomena Tom observed was that the gypsy moth caterpillars decided he was a tree waiting to be munched up. Standing on a ledge of Catskill sandstone one afternoon, he noticed that dozens of the little beasts were streaming toward him from all directions. When he moved several yards away, all of the caterpillars raised their heads like little submarine periscopes and started searching for this tree with legs. As soon as they zeroed in on Tom, they all changed course in unison, and started streaming toward him again. That summer, Tom learned to take field notes quickly, and to keep on the move!

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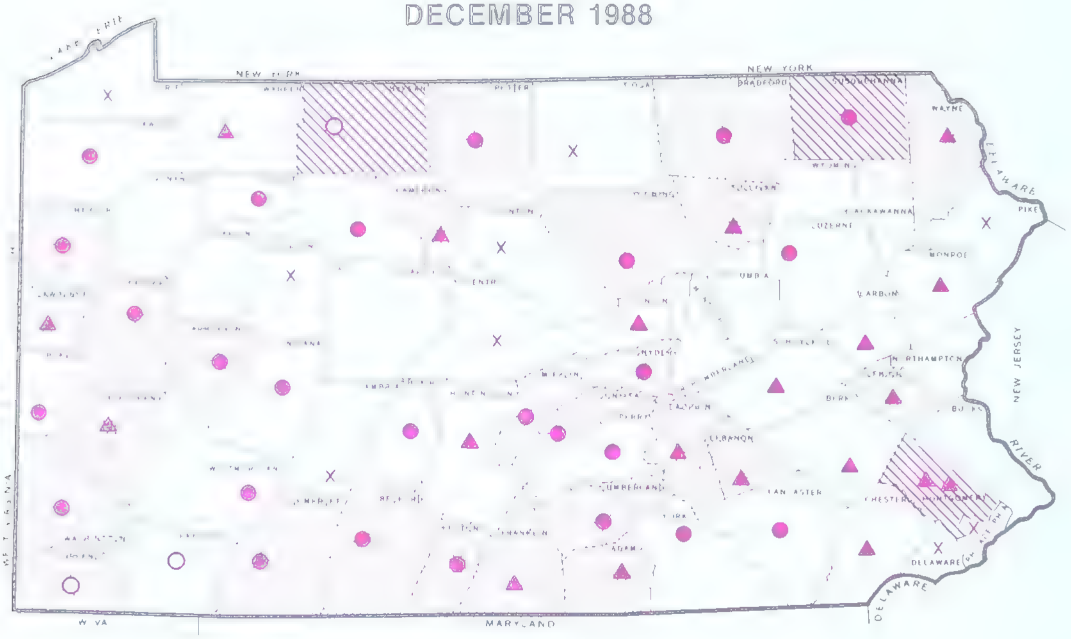
GROUNDWATER-RESOURCE MAPPING

GROUNDWATER LEVELS
FOR
DECEMBER 1988



EXPLANATION

○	●	△	▲	×	▨	☐	☐
Above last year	Below last year	Above last year	Below last year				
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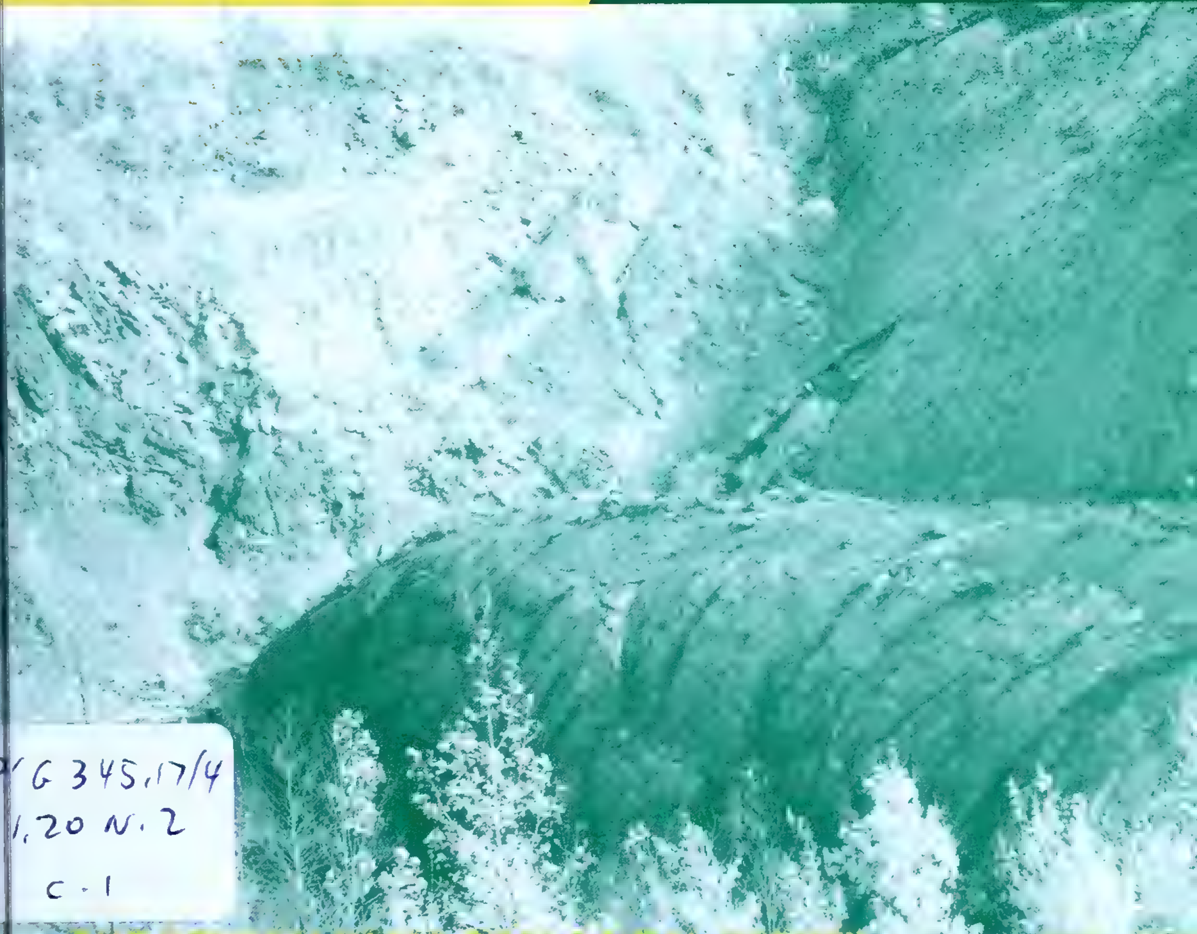

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ON THE COVER: The great "whaleback" at the Bear Valley strip mine, 1.8 miles southwest of Shamokin, in Coal Township, Northumberland County. This three dimensionally exposed anticline affects rock strata in the Mammoth coal zone of the Pennsylvanian-age Llewellyn Formation. Photograph by R. P. Nickelsen, Bucknell University.

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JUN 02 1989

The Future of Critical Minerals

The modern crisis of availability of critical and strategic minerals may yet make one world in which people will finally be forced to live together in harmony. Or, it may make further global conflict inevitable. If we look at the current spate of conflicts induced by nationalism and cultural vehemence and the inhumane treatment of people by each other and we project this behavior into the future, the scene is not a pleasant one. The unknown factor is whether this our human species can adapt to the finite limitations of natural resources of the earth or can discipline itself to use the earth's systems to sustain civilizations.

One hundred years ago, when minerals began to be extensively developed, the world had 1.9 billion people. Now we have 5 billion. All reasonable projections tell us that we will have 12 billion in the next 100 years. Using currently known resources and technologies, this growth demands that we will have to develop four times the amount of mineral, energy, and water resources as are currently developed. Responsible stewardship also demands that we consider the needs of the civilizations of the centuries beyond.

Citing our own national needs as an example, the U.S. Department of Interior lists as critical and strategic such minerals as the platinum group of metals, chromium, manganese, vanadium, and rutile. For these there are little or none at all to be found within the United States at any reasonable present or projected future cost. Although manganese may eventually be producible from nodules on the sea floor in the U.S. Exclusive Economic Zone, at present this is not economically feasible. Many other nations likewise lack essential mineral resources.

Resource problems are thus no longer national (if they ever were); they are global problems. Many of the largest resources of critical minerals are located in countries whose political behavior is either hostile or repugnant to the United States, such as South Africa. We face the dilemma of either devising ways to cooperate with them or we must change or reduce the standard of living to which we are accustomed. For example, China with its large, geologically unexplored areas is likely to become the major producer of many critical minerals on which we now depend.

We must learn to accept that the finite resources of our planet, such as fossil fuels and minerals, cannot sustain unlimited growth of population. As the carrying capacity of the earth is approached, the quality of life that most Americans enjoy will

(continued on page 16)

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IN MEMORIAM

John Oleksyshyn

1901–1987

John Oleksyshyn, educator and research geologist, died of heart failure on December 19, 1987, at the age of 86. He will be fondly remembered by his students and colleagues for his integrity, for his dedication to his work and his family, and for never inching away from his fundamental values and beliefs. His recent work on the Pennsylvanian flora of the Anthracite region made his name familiar to many paleontologists in Pennsylvania and the United States, both professional and amateur, who may yet know little of his extraordinary life.

Ivan (John) Oleksyshyn was born in Chreniv, Austria (Poland since 1923), on September 1, 1901, to a family of Ukrainian descent. During World War I, he served as a second lieutenant in the Ukrainian National Army and became a prisoner of war of the Polish occupation forces. Following his release in 1921, he eventually received his B.S. (1928) and M.S. (1929) in geology from the Jan Kazimierz University in Lvov. After teaching stints at several eastern European universities, he returned to school after World War II and obtained his Ph.D. in geology and mineralogy from Leopold-Franz University in Innsbruck, Austria.

In 1949, John came to the United States as a displaced person and acquired a position as a bacteriological technician at Jefferson Medical College in Philadelphia in 1953. He received his citizenship in 1954. He was finally able to resume his professional career when he was hired as an assistant professor of geology at Boston University in 1955. Within eight years, he had been promoted to full professor. A year after retiring from Boston University in 1967, John returned to Jefferson Medical College as a part-time microbiologist. He continued until 1984, when his health prevented his continued employment.

John Oleksyshyn carried on prodigious paleontologic research throughout his entire adult life. He was especially well known for his work on Miocene invertebrate paleontology of Europe and Carboniferous paleobotany of the northeastern United States. He wrote two landmark paleobotanical reports on the Pennsylvania anthracite fields: *Plant fossils from the anthracite coal fields of eastern Pennsylvania* (published in 1982 and reprinted in 1988) and *Fossil plants from the Abbott coal-bed horizon, Northern Anthracite field of eastern Pennsylvania* (to be published in 1990).

In John Oleksyshyn the geological profession has lost one of its most dedicated and meticulous practitioners—a man of exceptional qualities as a scientist, teacher, and friend.

From a Geological Society of America Memorial by Paul C. Lyons, U.S. Geological Survey.

The Eckley Whalebacks

by Jon D. Inners and Leonard J. Lentz
Pennsylvania Geological Survey

A major problem facing geologists in this era of "on-again, off-again" environmental consciousness is the loss of significant rock exposures and their outcrop data through reclamation of mines and quarries. Many a field geologist has seen his favorite sites destroyed through the mandated (and usually necessary) removal or burial of dangerous and often unsightly highwalls. The Pennsylvania Geological Survey has long had a program of photographing, sampling, and describing ephemeral strip-mine highwalls in the bituminous coal fields (Project TASIC—"Temporarily Available Stratigraphic Information Collection"). The Survey is only now starting similar data collection in the Anthracite region. Since our interest in anthracite strip mines centers as much on the temporarily exposed geologic structures as on the rock strata, we present here a detailed description of some unusual structures recently discovered in a strip mine near Eckley Miners' Village in the Eastern Middle Anthracite field, Luzerne County.

This paper concerns two "whalebacks," both of which were well exposed as late as the spring of 1986. But what, you ask, is a "whaleback"? To the anthracite miner, a whaleback is a broad roll in the "bottom rock" that brings the coal bed closer to the surface and makes strip mining somewhat easier. To the geologist, it is a three dimensionally exposed, doubly plunging, small third-order (wavelength ∼100 to 500 feet) anticlinal fold within the floor of a coal stripping. The resemblance to a whale is increased by the dark-gray to black, shaly "seat rock" (bottom rock) that commonly forms the rounded surface of the fold. Best known of the many whalebacks in the Anthracite region is the great Bear Valley leviathan near Shamokin (cover photo), made famous by the detailed geological investigations of Nickelsen (1979, 1983, 1987).

The Eckley whalebacks are located in an abandoned and partially backfilled strip mine on the southwest side of SR 2051, 1.5 miles southeast of Eckley, Foster Township, Luzerne County (40°58′56″N/75°50′11″W, Weatherly quadrangle; Figure 1). They lie near the east end of the Hazleton basin between Buck Mountain subbasins No. 2 (north) and No. 6 (south), approximately 400 feet south of the axis of the Hazleton syncline.

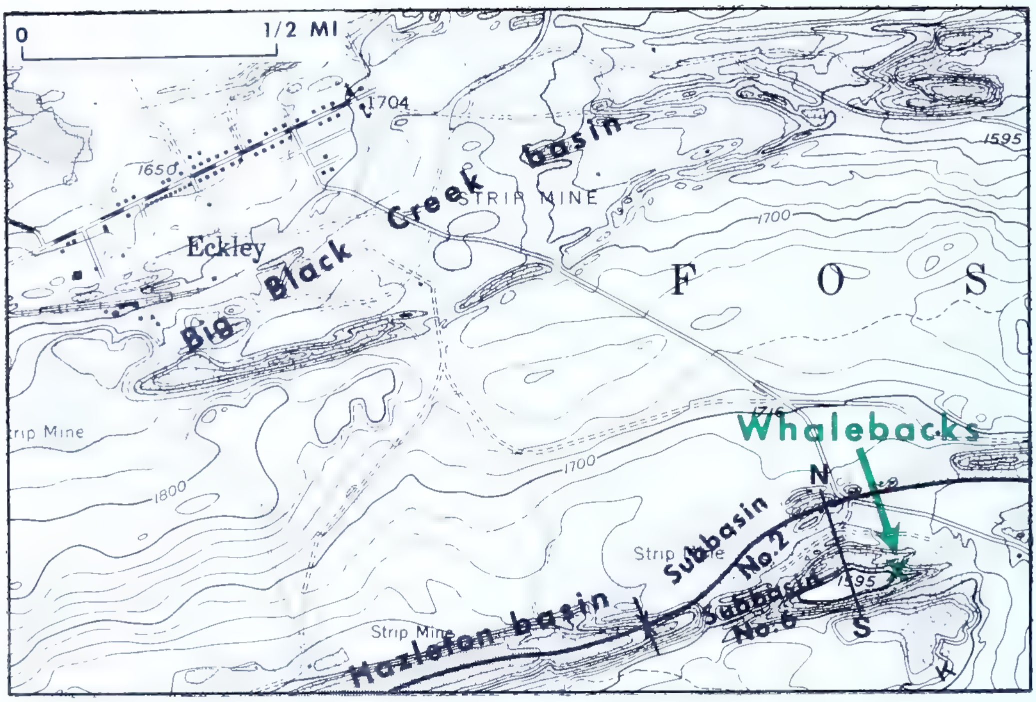

Figure 1. Location map, showing the coal basins and subbasins in the vicinity of Eckley, the site of the whalebacks, and the approximate line of the cross section in Figure 6.

Both structures expose rocks of Middle Pennsylvanian age that lie just below the Buck Mountain (No. 5) coal bed at the base of the Llewellyn Formation. One fold is mantled by dark-gray, rootworked, silty claystone that represents the seat rock of the coal bed; the other exposes the uppermost bedding plane of a light-gray, medium- to coarse-grained sandstone sequence (technically in the Pottsville Formation) that directly underlies the claystone seat rock.

The whalebacks consist of two *en echelon* (i.e., in steplike arrangement) anticlines—a low "roll" to the west and a higher, partially wooded knob to the east (Figure 2). Both structures have wavelengths of about 275 feet and wave heights of about 150 feet. The western whaleback plunges 8 degrees toward N88°W and 8 degrees toward S85°E (Figure 3a), and the exposed west end of the eastern fold plunges 32 degrees toward S85°W (Figure 3b). This latter plunge is extremely steep and considerably exceeds that of any other whaleback anticline that we have seen in the Eastern Middle field. (The Bear Valley whaleback—in the Western Middle field—plunges only 12 degrees at its well-exposed eastern end.)

Whereas the western whaleback is simply an anticlinal fold exhibiting two approximately perpendicular sets of planar, quartz-

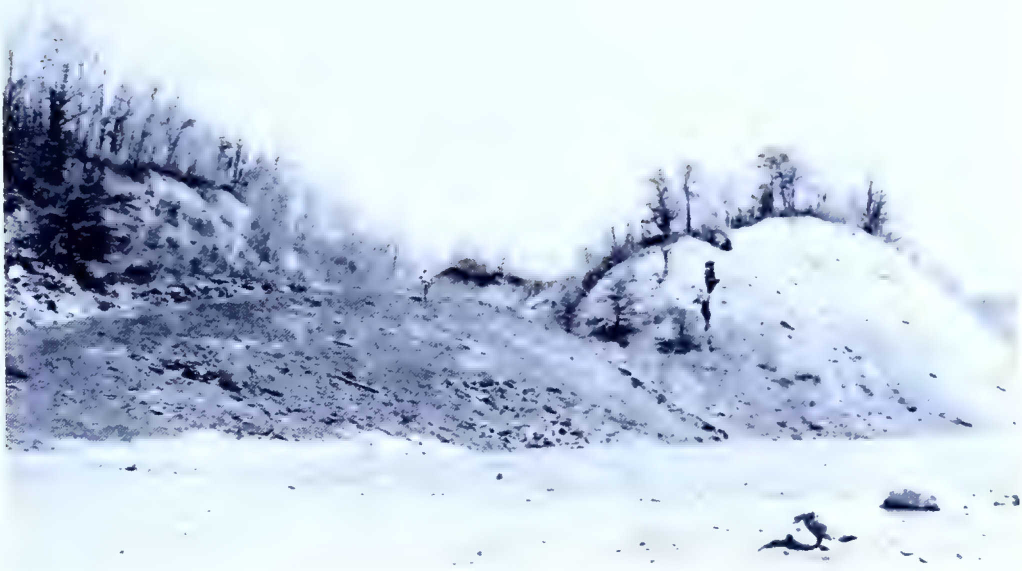

Figure 2. The Eckley whalebacks, as they appeared in April 1986. Looking east. The western fold (in the left foreground) has since been partially covered with spoils. The steep limbs and sharp plunge of the eastern whaleback (in the right background) have caused a peeling off of its original mantle of dark-gray claystone. Note the open fracture on the nose of the latter structure.

mineralized fractures—one nearly parallel to the strike of bedding and the other parallel to the dip direction (Figure 3a)—the eastern fold is much more complex. Its north limb is locally offset by a subvertical wrench fault that strikes N26°W (Figure 3b), and its south limb is cut by a conspicuous south-directed, folded thrust fault (Figure 4). Straight slickenlines on the wrench fault plunge 36 degrees to the northwest (Figure 3b), and, together with the minute, but distinct, "steps" on the slickensided surface, indicate an oblique right-lateral sense of motion (Figure 5). In addition, the west-plunging nose of the eastern whaleback is split by a ragged tension fracture ("fault") up to 2 feet wide, on which the north side has dropped down about 5 feet.

Figure 6 is a north-south cross section through the area based on mine sections supplied by Beltrami Enterprises and on exposures in a stripping directly to the north that cuts into the north side of the western whaleback (arrow). Note the overturned fold in the rock strata (interbedded dark-gray sandstones and shales) overlying the Buck Mountain coal bed and the broadly arched floor of subbasin

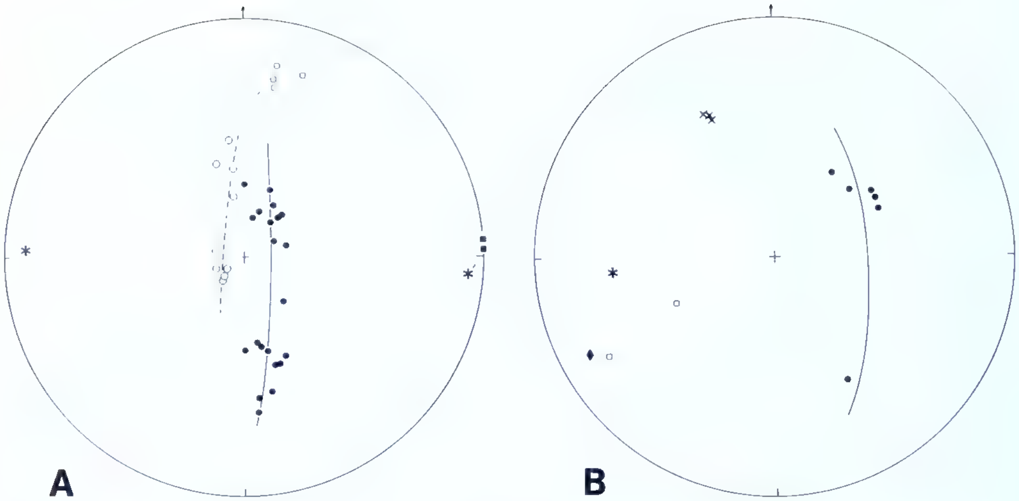

Figure 3. Stereograms (equal-area, lower hemisphere projections) of structural data from the Eckley whalebacks.

A. Western whaleback (●, pole to bedding, west end; ○, pole to bedding, east end; □, pole to strike-parallel fracture; ■, pole to dip-parallel fracture; *, west plunge; *′, east plunge; solid line, π-circle defined by bedding poles at west end; dashed line, π-circle defined by bedding poles at east end).

B. Eastern whaleback (●, pole to bedding; □, pole to fracture; ♦, pole to wrench fault on north limb; X, slickenline on wrench fault; *, west plunge; solid line, π-circle defined by bedding poles at west end).

No. 6. The Buck Mountain itself is 15 to 20 feet thick and consists of several benches of low-ash anthracite separated by shaly partings up to 6 inches thick. To the east this thick vein splits into two distinct coal beds up to 10 feet apart (C. Soroka, Beltrami Enterprises, personal communication, 1988).

When and how did these folds, faults, and fractures originate? All of the major structures of the Anthracite region formed during the Alleghanian orogeny, about 250 million years ago, at the climax of the collision between the North American and African continental plates. Like the Bear Valley whaleback, the Eckley folds were probably deformed beneath an overburden of 3 to 5 miles at a temperature of at least 200°C (Nickelsen, 1983; see Levine, 1986).

Of the six stages of the Alleghanian orogeny that Nickelsen recognized at Bear Valley, only two are well represented at Eckley. The prominent thrust fault on the south limb of the eastern whaleback (Figure 4) is probably similar to a Stage IV (pre-folding) thrust seen on the north limb of the Bear Valley whaleback (Nickelsen, 1979, Figure 7). Stage V is represented by the whaleback folds and the synclinal folds forming the subbasins. The planar fractures that cut the folded bedded surfaces of both whalebacks may also belong mainly

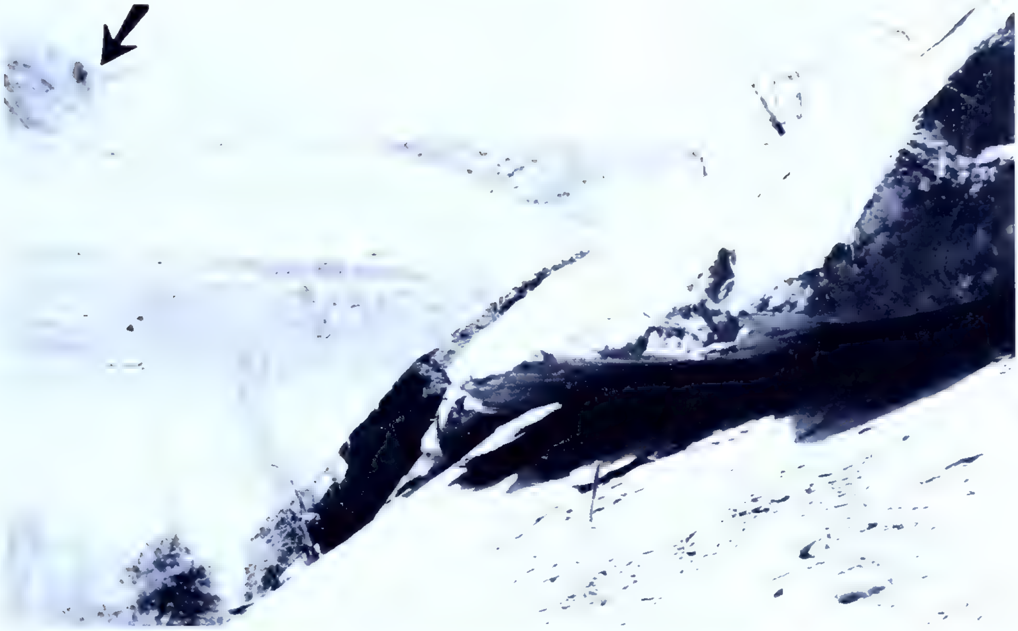

Figure 4. Folded thrust fault on the south limb of the eastern whaleback. Looking west. The Buck Mountain footwall on the south side of the basin is barely visible to the extreme left (arrow). The hammer is 11 inches long.

to this stage. Only the right-lateral wrench fault on the north limb of the eastern whaleback does not fit readily into Nickelsen's scheme. It appears to postdate the folding (straight slickenlines), but the movement sense is wrong for it to have formed by Stage VI extension parallel to the fold hinge (see Nickelsen, 1979).

The origin of the wide crack on the eastern whaleback (Figure 2) is unclear. It is probably related in some way to the early underground mining of the Buck Mountain on the north limb of the fold, where

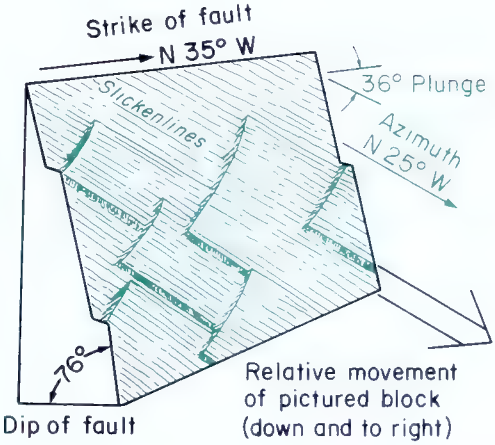

Figure 5. Sketch of slickenlines and "steps" on the quartz-mineralized surface of the wrench fault on the north side of the eastern whaleback, showing the relative movement of rock on either side of the fault.

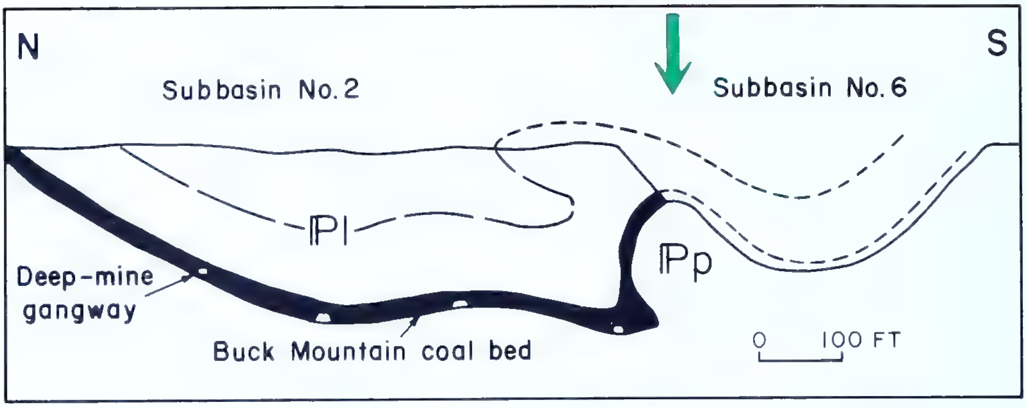

Figure 6. Slightly generalized cross section across the Hazleton basin in the vicinity of the whalebacks (ℙp, Pottsville Formation; ℙl, Llewellyn Formation; arrow indicates the western whaleback anticline).

the sandstone is overturned slightly and overlies the coal bed. If a large mine void were excavated there, settlement of the massive sandstone could create tensional stresses that would rend the nose of the fold.

In only a few years, much of what we can now see in the Eckley strip mine will be covered over and vegetated, and weathering will soon after efface the little that remains above the backfill. No more will the geological investigators of this part of Luzerne County be able to exclaim like Ismael in Melville's *Moby Dick*: "And lo! close under our lee, not forty fathoms off, a gigantic Sperm Whale lay rolling in the water like the capsized hull of a frigate, his broad, glossy back, of an Ethiopian hue, glistening in the sun's rays like a mirror." With this constant man-made and natural flux in mind, perhaps we should try all the harder to preserve the great whaleback at Shamokin (which is in danger of being covered by spoils when stripping operations resume in nearby areas). In this way, future generations will be assured of having at least one such "window" into the geologic foundation of the once-prosperous Pennsylvania anthracite industry and the past turbulent history of the earth.

We are indebted to Louis Beltrami and Charles Soroka of Beltrami Enterprises, Hazleton, Pennsylvania, and Vince Shikora of Tresckow, Pennsylvania, for supplying information used in preparing this article.

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COMMEMORATE THE CENTENNIAL OF THE JOHNSTOWN FLOOD

at the

1989 Field Conference of Pennsylvania Geologists

The 54th Annual Field Conference of Pennsylvania Geologists will convene in Johnstown, Pennsylvania, October 5–7, 1989, at the site of the famous 1889 "Johnstown flood." Special features of the 1989 Conference are as follows:

- Float trip (pre-meeting) on the Youghiogheny River between Ohiopyle and Confluence to see Venango Group stratigraphy—limit 40 people
- Underground Kittanning coal mine (pre-meeting) to see relationship of geology to underground mining problem—limit 20 people.
- Reception and preview of field trips at the Johnstown Flood Memorial Museum.
- Upper Devonian–Pennsylvanian stratigraphy and structure in and around the river gorges through the Laurel Hill and Chestnut Ridge anticlines.
- "Windfall"—songs of the rivers, mountains, mines, and floods following the annual banquet.

Early registration is recommended for the limited spaces on each of the optional pre-meeting trips. Registration information will be sent in early August. If you are not on the current Field Conference mailing list and wish to attend the 1989 Conference, please write to the Field Conference of Pennsylvania Geologists, c/o Pennsylvania Geological Survey, P. O. Box 2357, Harrisburg, PA 17105.

NEW PUBLICATIONS

THE STATE GEOLOGICAL SURVEYS—A HISTORY

This comprehensive volume was published by the Association of American State Geologists in recognition of the major role that the State Geological Surveys have played in geologic mapping and research accomplished in the United States over the past 150 years. Diverse in size, name, and detailed functions, each of the 50 State Surveys has the basic responsibility to delineate the geologic framework and resources of the respective state.

Edited by retired Pennsylvania State Geologist Arthur A. Socolow, this illustrated, hard-covered, 500-page book contains the history, organization, and functions of the 50 State Geological Surveys in individual chapters prepared by the respective Surveys. It is a record replete with scientific achievements, human drama, bureaucratic struggles, and, most important, service to the public.

Geologists in government, academia, and industry, as well as all who are interested in geologic achievements, will find this volume informative and thoroughly readable.

The State Geological Surveys—A History may be ordered from the Geological Survey of Alabama, P. O. Box 0, Tuscaloosa, AL 35486. The price of $20 includes shipping. Checks should be made payable to *Association of American State Geologists*.

STUDIES OF EARLY MESOZOIC BASINS

U.S. Geological Survey Bulletin 1776, a compilation titled **Studies of the Early Mesozoic Basins of the Eastern United States,** is now available for distribution. Many of the sections in this 423-page report pertain to the geology of Pennsylvania. One of the more exciting papers concerns a palladium anomaly at Reesers Summit, York County. Based on cooperative sampling by the Pennsylvania Geological Survey and the U.S. Geological Survey through the York Haven Diabase at Reesers Summit, the report contains a description of a 300-foot-thick zone containing an anomalous concentration of palladium. The presence of a confirmed anomaly of a platinum-group element in a ferrogabbro suggests that significant exploration targets exist within Pennsylvania.

Other interesting papers deal with various types of copper occurrences within the Mesozoic and the sedimentary, stratigraphic, and tectonic aspects of the Mesozoic basins in Pennsylvania. Various interpretations of the fluvial-deltaic-lacustrine sequences are presented. Some of these papers also deal with the petroleum, uranium, and base-metal characteristics and potential in this rift-basin setting.

Bulletin 1776 is available from U.S. Geological Survey, Books and Open-File Reports, Federal Center, Box 25425, Denver, CO 80225. Prepayment of $20 (includes postage) by check or money order payable to the *Department of the Interior-U.S.G.S.* should accompany each order.

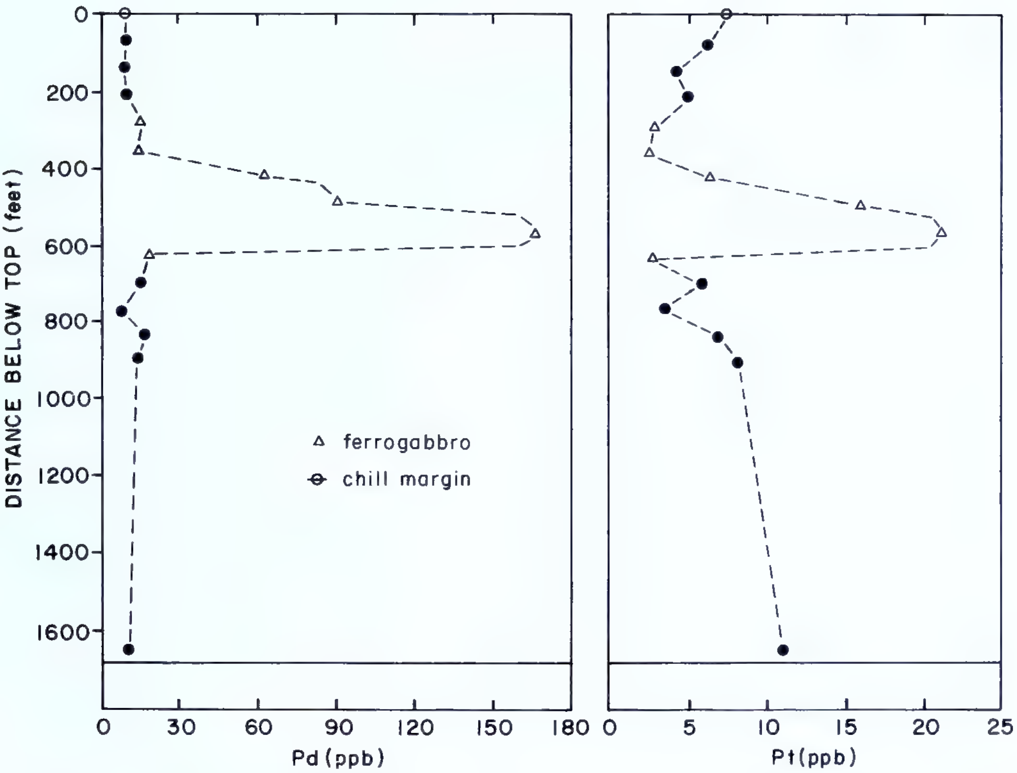
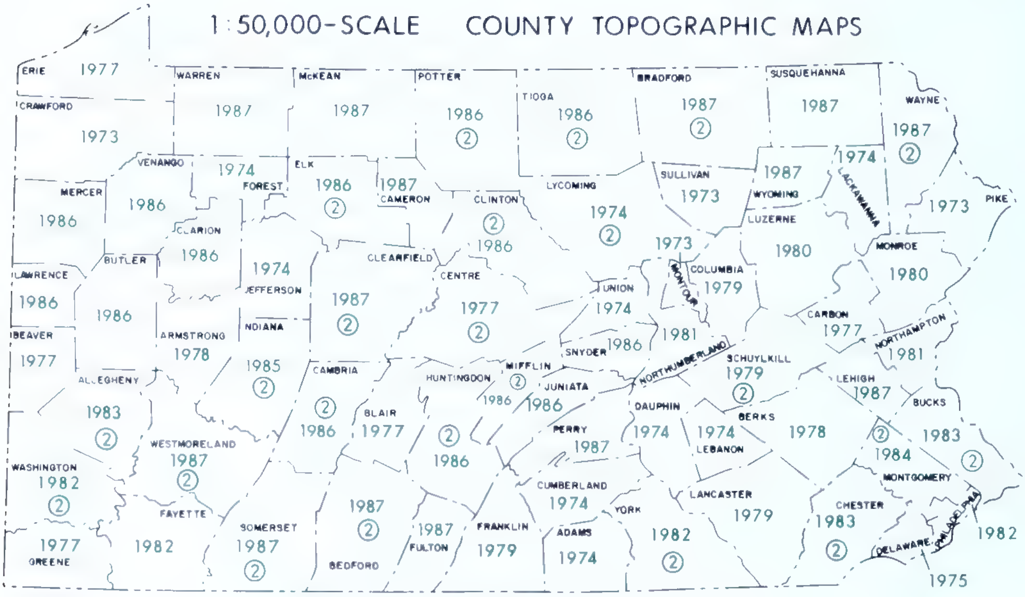


Figure 1. Distribution of palladium (Pd) and platinum (Pt) in York Haven Diabase, Reesers Summit, York County, Pennsylvania (slightly modified from Gottfried, David, and Froelich, A. J. (1988), *Variations of palladium and platinum contents and ratios in selected early Mesozoic tholeiitic rock associations in the eastern United States,* in U.S. Geological Survey Bulletin 1776, p. 338).

COUNTY TOPOGRAPHIC MAP SERIES NOW COMPLETE

With the publication of Westmoreland County, the 1:50,000-scale county topographic map series of Pennsylvania is complete. Although the series was started in 1973 with the publication of Lehigh County by the Pennsylvania Geological Survey, preparation of the remaining Pennsylvania county maps was assumed by the U.S. Geological Survey as part of its national program of intermediate-scale maps. Pennsylvania is now one of three states (along with Colorado and Connecticut) that have topographic map coverage at the 1:50,000 scale; these three states plus Iowa and Wisconsin are the only states whose county topographic map series are complete.

Nine county maps have been released for public sale in the past 12 months. These are Cameron (part of this map is shown on the following page), Clearfield, Juniata, Lawrence, Somerset, Wayne, Westmoreland, and Wyoming. In addition, Lehigh County, published in 1973, and formerly available as Map 39 of the Pennsylvania Geological Survey, has now been replaced by the 1987 U.S. Geological Survey edition. Copies of each have been distributed to local legislators, county and township commissions, and county planning agencies for examination.



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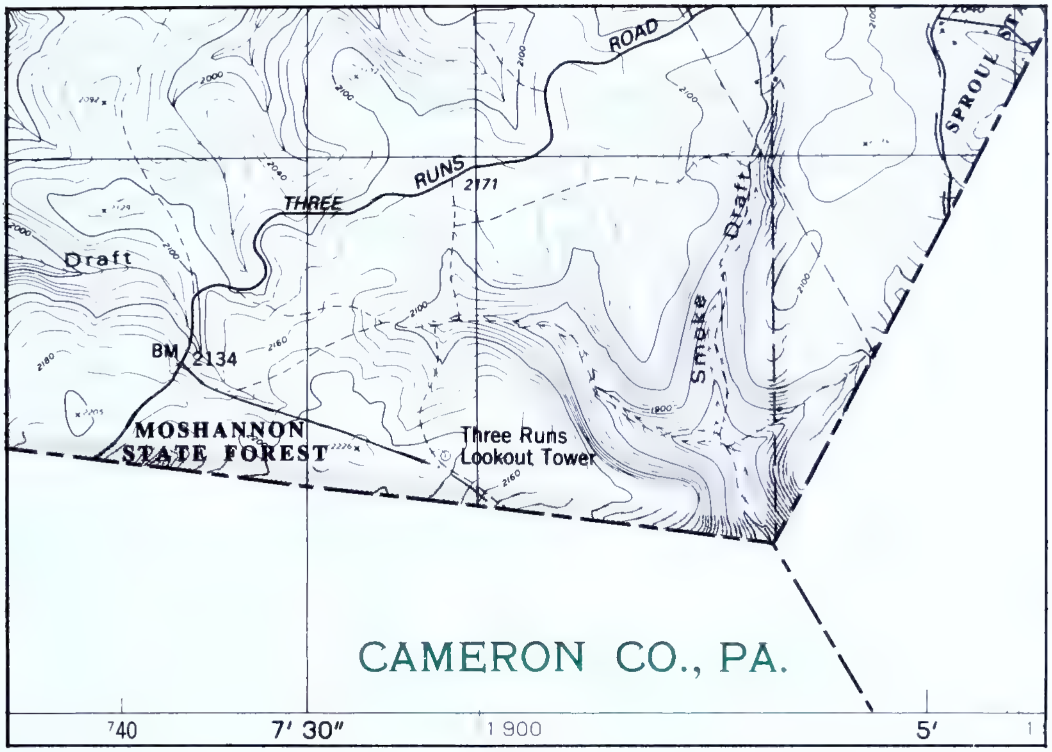
② County is printed on two sheets



These maps may be purchased from the U.S. Geological Survey, Map Distribution, Box 25286, Federal Center, Denver, CO 80225. The cost of each sheet is $4.50 (if the map is printed on two sheets, the price is $9.00; refer to the index map for the number of sheets in each county). Prepayment is required; make checks payable to *U.S.G.S.* A $1.00 handling charge should be included on orders of less than $10.00.

For more information, contact the Pennsylvania Geological Survey library, the National Cartographic Information Center (NCIC) Affiliate, telephone 717-783-8077; or contact NCIC Headquarters at the U.S. Geological Survey, telephone 1-800-USA-MAPS.

The next phase of the county map series is the revision of the oldest maps; this phase has been started with a pilot project focused on Montour County. One purpose of the project is to determine the best method for rapid updating and republication of each map. The map information on Montour County dates from prior to 1973, the date of original compilation, and will be revised from modern aerial photography obtained as part of the NAPP (National Aerial Photography Program), which started in Pennsylvania in 1987. In planning for revision of these county maps, we seek comments on their utility and how they might be improved. Please address your comments to State Geologist, Department of Environmental Resources, P. O. Box 2357, Harrisburg, PA 17105.

State Geologist of Ohio Selected from Pennsylvania Geological Survey Staff

Thomas M. Berg, Associate Director of the Pennsylvania Geological Survey, and Chief of the Geologic Mapping Division for the past decade, was selected to become the new State Geologist of Ohio. Tom, who spent 24 years with the Pennsylvania Geological Survey mapping in the bituminous coal fields, the Pocono Plateau, and the Ridge and Valley province, became the 11th State Geologist of Ohio on March 13, 1989, preceded in the position by such eminent geologists as William W. Mather, John S. Newberry, Edward Orton, and George White. The history of the Ohio Geological Survey nearly parallels that of the Pennsylvania Geological Survey. The Ohio Survey began in 1837, one year after the First Survey began in Pennsylvania, and is now in its fourth organizational structure, as is the Pennsylvania Geological Survey.

Tom became well known in Pennsylvania through his compilation work on the 1980 geological map, which significantly improved upon prior editions. As part of this compilation, Tom did extensive field reconnaissance for the north-central part of Pennsylvania. This work evolved into remapping of the bedrock and surficial geology of Warren County, a project that became his final one as a member of the Pennsylvania Geological Survey. This new map will appear as part of a report on the groundwater resources of Warren County being prepared by the Survey's Environmental Division in cooperation with the U.S. Geological Survey.

While a member of the Pennsylvania Geological Survey, Tom also became well known for his work on *Archanodon* (the upper Paleozoic clam burrow), Upper Devonian and Lower Mississippian stratigraphy, and mapping of glacial and surficial deposits. Important products that resulted from Tom's lead role in the 1980 geologic map were the first-ever published correlation chart of Pennsylvania rocks and the atlas of preliminary geologic quadrangle maps of Pennsylvania (Map 61), which has been one of the most useful sets of maps in the Survey's history.

We are very sorry to lose the experience, knowledge, and companionship of Tom, but we are glad that another state has recognized his capabilities and has selected Tom to lead its Survey. We wish Tom all success.

We trust that, much as in the celebratory cake feasted upon on Tom's last day, there will be no geological or administrative border faults between Ohio and Pennsylvania.

ADMINISTRATIVE ASSISTANT EARNS ACHIEVEMENT AWARD

Cheryl L. Cozart, an Administrative Assistant in the Oil and Gas Geology Division in Pittsburgh, received the Secretary's Award for Outstanding Achievement at the Department's Employe Recognition Program Awards Luncheon in October 1988. Ms. Cozart was honored for her outstanding work in developing several important data bases on the Division's Sperry IT/PC computers. These include, but are not limited to, data bases dealing with oil and gas well statistics, oil and gas production, geophysical-log requests, and billing for copying services. Through the hard work of Ms. Cozart, the Division now has an easier task of collecting and disseminating information on oil and gas in Pennsylvania.

Flanking Ms. Cozart is Secretary of Environmental Resources Arthur A. Davis (left) and Deputy Secretary for Resources Management James R. Grace.

Pennsylvania Geologist Receives National Award

The Association for Women Geoscientists Foundation (AWGF) awarded its first Outstanding Educator Award to Dr. Maria Luisa Crawford of Bryn Mawr College. The award was given at a special breakfast on November 2, 1988, during the Geological Society of America National Convention in Denver, Colorado. The award was given by the Foundation in recognition of Dr. Crawford as an outstanding educator who has demonstrated excellence and commitment to the higher education of women students in the field of earth science. The award was doubly significant because it was given at the Centennial celebration of the Geological Society of America.

The AWGF was established by the Association for Women Geoscientists in 1983 to develop and fund innovative programs designed to encourage women to study earth science and to investigate career opportunities and advancement in the geoscience professions.

Dr. Crawford (Weecha to her colleagues) has provided a role model to many young women studying geology and preparing to enter geoscience professions. A researcher of the highest caliber, Weecha Crawford has chaired the Geology Department at Bryn Mawr for 12 years, published more than 80 papers and abstracts, and received more than a dozen National Science Foundation grants for her work. She is truly an inspiration to everyone in her field and has made major contributions to the geology of Pennsylvania.

(continued from page 1)

most probably suffer. This problem demands that our leaders who establish state and national policies understand the complexity and implications of availability of natural resources on which we depend. The State and U.S. Geological Surveys, as well as the U.S. Bureau of Mines, together can assist our state and national leaders by providing the framework for investigating and understanding natural-resource availability.

Donald M. Hoskins

Donald M. Hoskins
State Geologist

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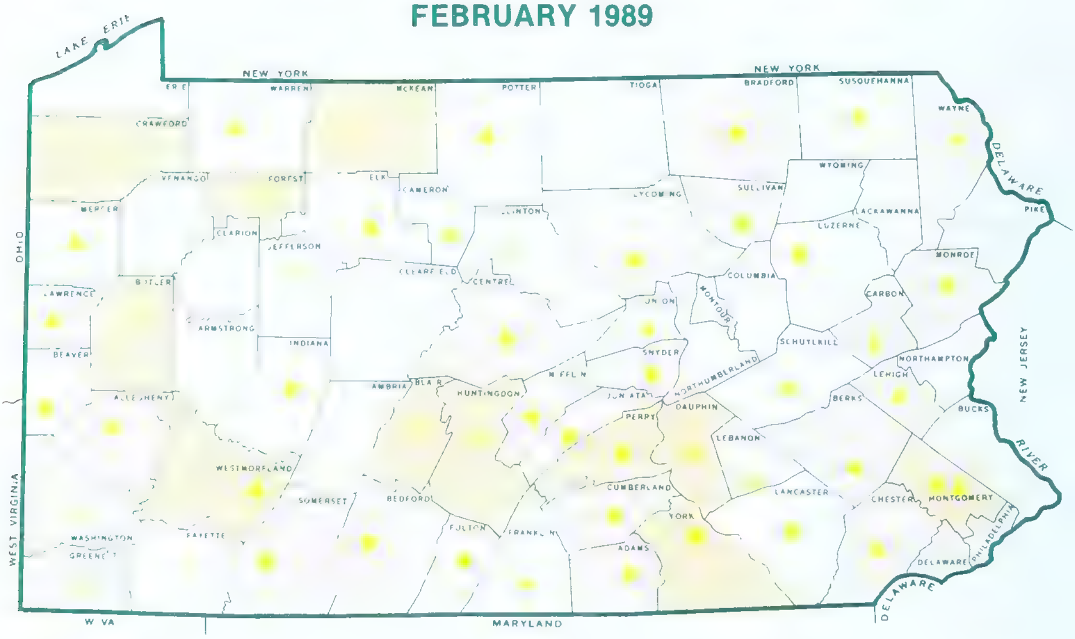
TOPOGRAPHIC MAPPING
GROUNDWATER-RESOURCE MAPPING

GROUNDWATER LEVELS FOR FEBRUARY 1989



EXPLANATION

Observation well: ● Above last year; ● Below last year

Observation well equipped with data-collection platform: ● Above last year; ● Below last year

No data

▨ High

☐ Normal range

☐ Low

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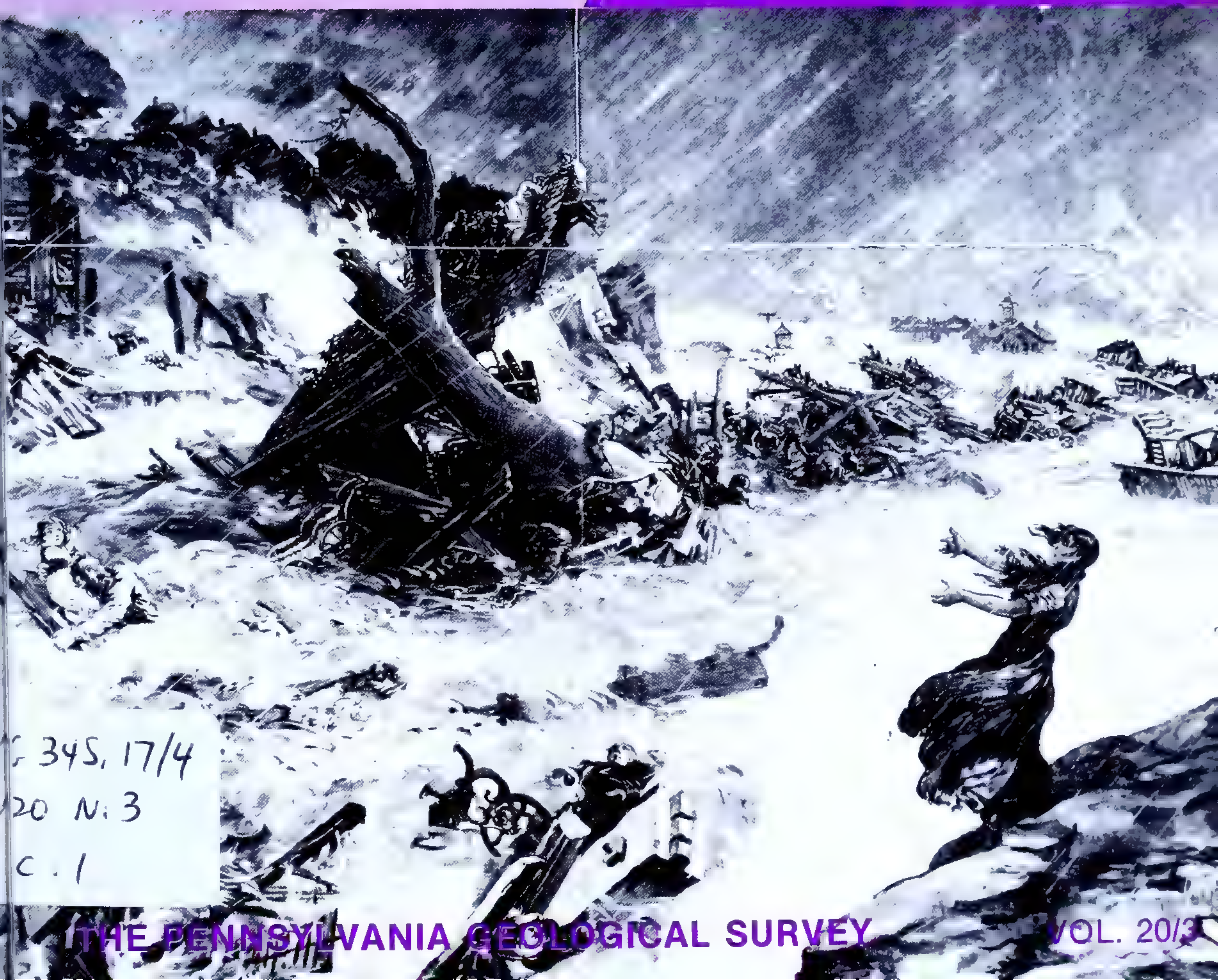

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THE PENNSYLVANIA GEOLOGICAL SURVEY VOL. 20/3

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ON THE COVER: Reproduction of a copper-plate engraving by W. A. Rogers of the scene at the railroad bridge during the Great Johnstown Flood of May 31, 1889. Provided courtesy of Alice Marshall, Camp Hill, Pennsylvania, from an original copy of *Harper's Weekly* of June 15, 1889.

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Editors, Christine M. Dodge and Donald M. Hoskins.

Articles may be reprinted from this magazine if credit is given to the Topographic and Geologic Survey.

VOL. 20, NO. 3 **JUNE 1989**

SEP 25 1989

The Lessons of the Conemaugh

John Wesley Powell, the fiery, one-armed Civil War veteran, explorer of the Colorado River, found lessons to be learned from the Great Johnstown Flood of May 31, 1889. The centennial of the "Great Flood" is commemorated throughout Pennsylvania this year in newspaper and magazine articles, on the cover of this issue, and in many events in Johnstown, including the 1989 meeting of the Field Conference of Pennsylvania Geologists.

In 1889, Powell was attempting to map our nation by preparing topographic maps of eastern states through the U.S. Geological Survey and of the arid land states by the Irrigation Survey. He wrote in the *North American Review* that "the lesson of the Conemaugh," the title of his article, was "a very old one; that must be taught to mankind again and again." Powell was a visionary who believed in long-range planning. He knew that in order to avoid disasters caused by natural events it is essential to have foreknowledge of all of the natural conditions and expectations of an engineering project. Careful topographic and hydrographic surveys are a necessity prior to construction of dams and reservoirs.

The same needs exist today! Topographic maps must be continually updated; modern geologic and hydrogeologic surveys must be accomplished to provide the information needed for planning the wisest use of our land for the greatest public benefit.

A Footnote

Clara Barton, Founder of the American Red Cross, writing with Powell in the *North American Review*, spoke of the perplexities she and her Red Cross workers faced during the Great Johnstown Flood. A deluge of relief supplies was received, but none with indication of the contents. Needed items could not be found. Recent reports of the relief shipments to Armenia showed similar circumstances; boxes were unlabeled or in languages unknown to the recipients.

Some lessons are learned in disasters caused by natural events such as floods and earthquakes; others are quickly forgotten. Geologists must never forget, and, following the example of Powell, must never give up their efforts to teach the importance of our science to the commonweal of our state and nation.

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Donald M. Hoskins

Donald M. Hoskins
State Geologist

AN UNUSUAL AGGREGATE SOURCE: GETTING THE SQUEAL OUT OF THE PIG IRON

by Robert C. Smith, II, and Samuel W. Berkheiser, Jr.
Pennsylvania Geological Survey

Northwestern Pennsylvania has limited resources of high-friction construction aggregate suitable for maintaining and building high-use roads. However, Dunbar Slag Company, Inc., of Sharon, processes air-cooled slag from blast furnaces into a product that meets this and many other needs. As stated in an old adage, "One man's trash is another man's treasure"—and treasure this is! At one time, large dumps of this type of slag, which was considered to be trash, littered the landscape in the steelmaking area of Sharon, but no more.

Slag is the nonmetallic top layer of a melt formed during metal smelting, and "air-cooled blast-furnace slag" generally refers to waste material resulting from solidification of blast-furnace slag under atmospheric conditions. Air-cooled slag has certain physical and chemical characteristics that set it apart from the more common construction aggregates. Although not considered a true lightweight aggregate, the individual slag flows are blended with one another to weigh approximately 75 pounds per cubic foot compared to crushed stone, which typically weighs about 100 pounds per cubic foot. This low density means more volume per ton of material. Also, its rough, vesicular surface promotes excellent bonding in concretes. When crushed, air-cooled blast-furnace slag commonly tends to form cubical particles, another desirable physical property for construction aggregates. It is a tough, hard, PennDOT-approved aggregate that gives a high skid-resistance value to bituminous road surfaces. Table 1 lists typical ranges in physical properties of air-cooled blast-furnace slag.

ORIGIN AND PREPARATION OF PRODUCT. Dunbar Slag Company, Inc., processes air-cooled blast-furnace slag, a by-product of pig-iron production at Sharon Steel, at the rate of 1,200 tons per day. Slag availability is dependent on Sharon Steel's production of pig iron. As the molten slag is drawn off the nearby furnaces, it is poured into slag-buggies (ladle-like side-dump railroad cars), which take it on a half-mile journey to the slag dump. Here, the still-molten slag is dumped to form lava-like flows that are a few inches thick and extend up to 100 feet from the rail siding (Figure 1). The slag nearest the slag-buggies tends to be smooth and glassy; at the distal ends of the flows it is highly vesicular. Freshly poured slag is reminiscent of lava fields, complete with

Table 1. *Physical Properties of Air-Cooled Blast-Furnace Slag*

(From McCarl and others, 1983)

Property	Range
Unit weight	70–85 lb/ft^3
Absorption	1–6%
Bulk dry specific gravity	2.0–2.5

smoking fumaroles (Figure 2). The poured slag behaves much like basaltic lava, and if it were lava, it would be classified as pahoehoe because of its ropey texture. On windy days, a small amount of delicate glass fibers, analogous to "Pelee's hair" found in volcanic regions, forms near the buggies, only to be broken by later breezes. The slag also forms a small amount of glass that tends to attach itself to the walls of the buggy ladles and must often be knocked out. Because it has less time to react, this glass probably most nearly represents the bulk composition of the slag.

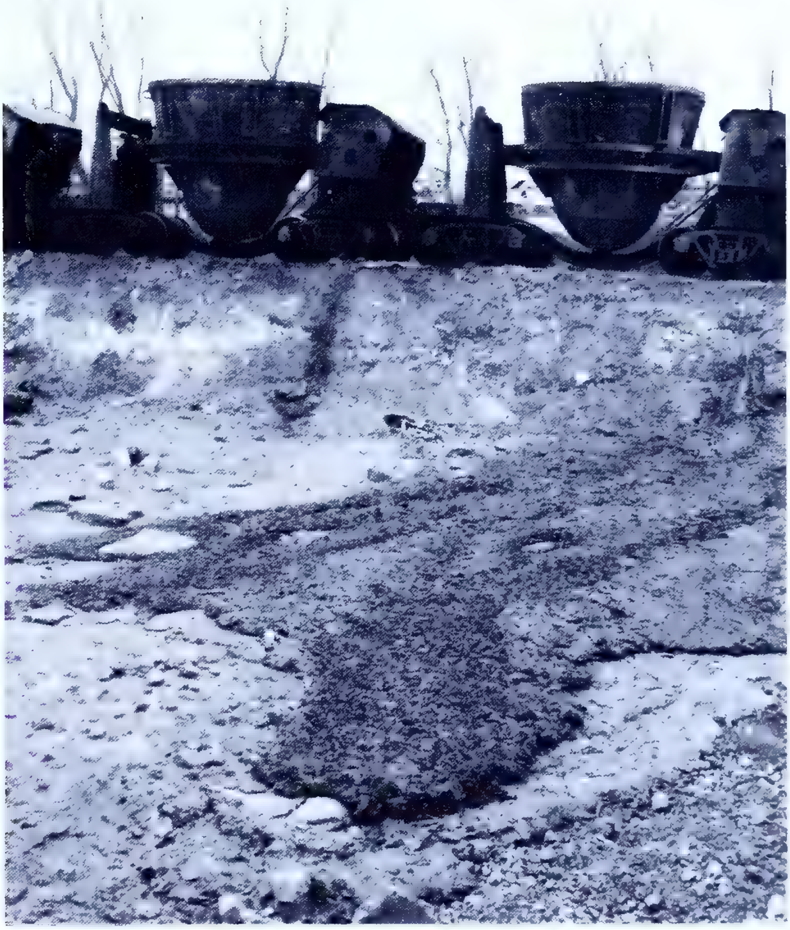


Figure 1. View of slag-buggies and freshly poured slag flow showing pahoehoe textures in the foreground.

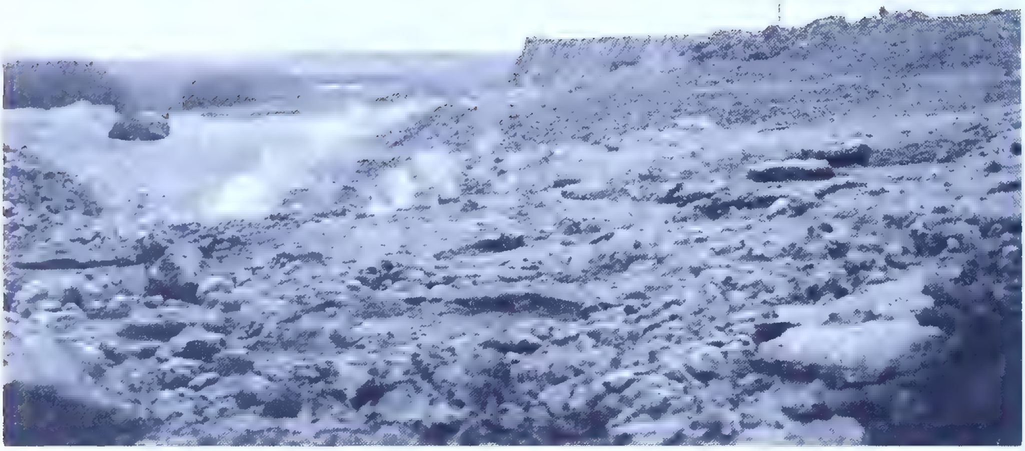


Figure 2. Overview of the largely mined-out slag dump parallel to the rail siding containing the slag-buggies (right side of photo). Notice the smoking fumarole-like effect from the still-molten slag.

Prior to processing, a loader-operator must blend each 15-ton haul-truck load of slag from the frothy distal ends of the flow with the more massive glassy portions near the head of the flow to ensure product consistency. Blending also controls absorption values. The processing plant consists of a primary jaw crusher in tandem with a secondary gyratory crusher. This equipment and screens are kept busy producing the more popular 1-inch and 3/8-inch materials. Metallic iron is removed magnetically and recycled back to the furnaces.

MARKETING. Bedrock sources of high-quality, PennDOT-approved aggregate are scarce in the northwestern part of the Appalachian Plateaus province because the rocks in that region are largely composed of unsound siltstone, mudstone, and claystone. Glacial sand and gravel are found in the region, but often fail to win approval as an aggregate source because much of the material was derived from the local, "substandard" bedrock. Most of the aggregate produced by Dunbar is sold within a 30-mile radius of Sharon and enjoys limited competition. According to Jim Barnicle of Dunbar Slag, who is also the newly elected President of the Pennsylvania Aggregates and Concrete Association, "because of its unique properties, air-cooled blast-furnace slag almost markets itself."

By virtue of its vesicular nature and density, construction aggregate made by this process presents a classical good news/not-so-bad news situation with respect to the consumer. The not-so-bad news is that bituminous concrete made with slag absorbs more asphalt, a costly raw material. The good news is that slag, which is sold by weight, is 20 percent lighter than traditional aggregate on a per-volume basis. For bituminous concrete, coarse aggregate, which slag can provide, makes up half of the matrix; the result is that the consumer gets 10 percent more bulk per ton of purchased product. The weight savings gained in the construction of high-rise buildings, roofs, and bridge decks using this material is a significant advantage.

Dunbar Slag Company, Inc., and its employees turn a waste product into a valuable mineral resource that makes life a little easier and safer. Credit is also due to the National Slag Association, which has been instrumental in developing uses, markets, and public acceptance of slag as a quality construction material.

REFERENCES

McCarl, H. N., Eggleston, H. K., and Barton, W. R. (1983), *Construction materials; Aggregates—slag,* in Lefond, S. J., editor-in-chief, *Industrial minerals and rocks,* 5th ed., New York, Society of Mining Engineers of the American Institute of Mining, Metallurgical, and Petroleum Engineers, v. 1, p. 111–131.

EXOTICALLY SCULPTURED DIABASE—AN ADDENDUM

by W. D. Sevon
Pennsylvania Geological Survey

The following paragraph should have appeared at the end of the section entitled "Potholes" in my recent paper on erosional forms at Conewago Falls (Sevon, 1989):

"Considerable research on the relationship of hydraulic vortices and riverbed nickpoints to the formation of potholes has been done by Glenn Thompson farther downstream along the Susquehanna River in Holtwood Gorge, southwestern Lancaster County, Pennsylvania (Thompson, 1988). His work strongly influenced development of ideas discussed in this paper, and his concepts about the initial position of pothole erosion may have greater applicability to Conewago Falls than is suggested here."

Sincere apologies to Glenn for my omission!

REFERENCES

Sevon, W. D. (1989), *Exotically sculptured diabase,* Pennsylvania Geology, v. 20, no. 1, p. 2–7.

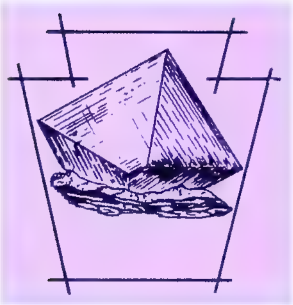
Thompson, G. H., Jr. (1988), *The Susquehanna River gorge at Holtwood, Pa.,* in Thompson, G. H., Jr., editor, *The geology of the lower Susquehanna River area: a new look at some old answers,* Harrisburg Area Geological Society Annual Field Trip, 7th, Guidebook, p. 27–44.

New USGS Publication Aids Rural Homeowners

If you already own or are considering ownership of a home in an area where private water supplies and septic systems are necessary, the booklet **Ground Water and the Rural Homeowner** should be of interest. Published by the U.S. Geological Survey, this excellent report provides important information on groundwater and the types of problems one might encounter. Tips are given on what to look for before purchasing or building in a rural area, how to avoid problems with a private well or septic system, and how to cope with a problem should it occur. For example, if building a home, drill the well before starting construction. This will help assure that an adequate supply of water is available.

The U.S. Geological Survey deserves compliments for preparing and publishing this very informative report that will be useful to a large number of citizens in the United States.

Single copies of the booklet are available free of charge by writing to Book and Open-File Reports Section, U.S. Geological Survey, Federal Center, Box 25425, Denver, CO 80225.

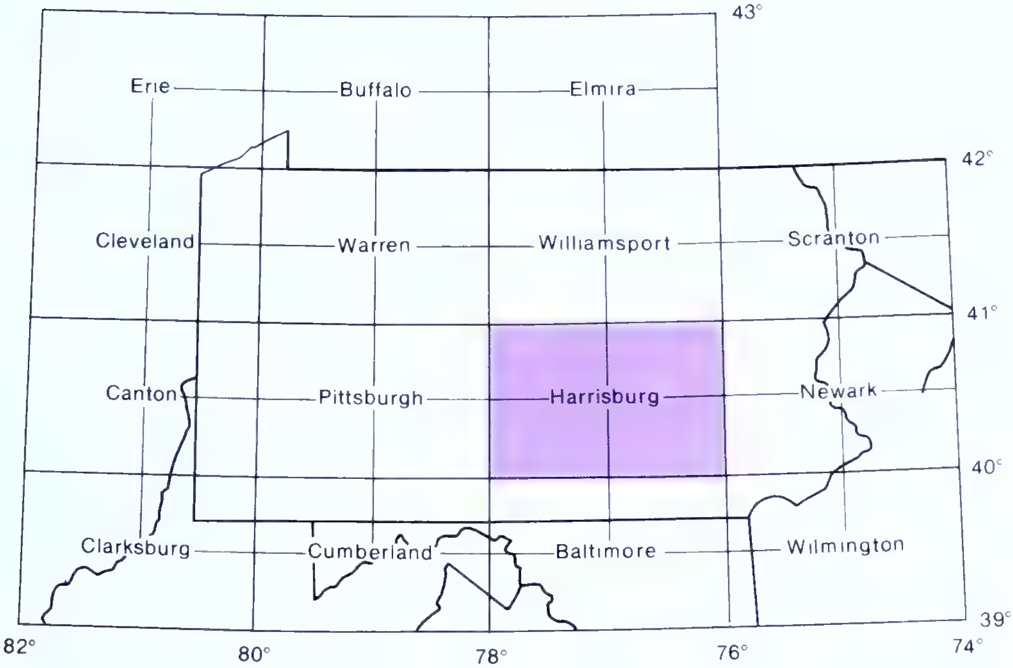


EARTH SCIENCE TEACHERS' CORNER

New Tool For Earth Science Teachers— Satellite Image Map of South-Central Pennsylvania

Based on the Harrisburg 2-degree map, a new type of map product, called a satellite image map, has been published for part of Pennsylvania. Composed of rectified images collected by the earth satellite Landsat–3 multispectral scanner (MSS), the image map is combined with the standard topographic map of the same area. The new map was prepared by the U.S. Geological Survey, in cooperation with the Pennsylvania Geological Survey.

The combination of image map and topographic map makes a useful educational tool for teaching about maps and how they portray actual and symbolized information. The standard 1:250,000-scale topographic map of the Harrisburg area is printed on one side of the new map. On the reverse is the image map, which is a mosaic of four different satellite images taken on May 4, 1982. The mosaic image is controlled to fit symbolized map features identified on the topographic map.



Colors on the satellite image map are predominantly red, but range from white, which represents smooth, cleared areas, to black, which represents deep, clear water. The Susquehanna River, which nearly bisects the area represented by the image map from north to south, appears as a broad black band, and islands in the river appear in dark to bright reds. The dominant red colors of the image map show areas of conifer trees, grasses, and crops. Urban areas and strip mines are in blue; the urban corridor from Lebanon to Carlisle is a very prominent east-west band, as are anthracite strip-mine areas. Deciduous trees, marshes, and fallow crops are in shades of gray. Fallow crop lands, together with growing crop lands portrayed in shades of red, create a densely packed gray-red "checkerboard" pattern in many agricultural areas.

By cutting along the central meridian, the topographic map and image map can be placed side by side so as to compare the scene collected by the Landsat–3 MSS with the cartographic symbols used in portraying topography, drainage, culture, and forested areas on the standard topographic map. As a further aid in the comparison of cartographic symbols to the MSS image, the Universal Transverse Mercator grid is printed on the image map, as well as on the topographic map.

The Pennsylvania Geological Survey has obtained a limited supply of these new maps, which will be sent to earth science teachers and other requestors at no cost until the supply is exhausted. Copies of the map may be obtained by writing to the State Geologist, Pennsylvania Geological Survey, P. O. Box 2357, Harrisburg, PA 17105. The maps are also available for sale by the U.S. Geological Survey, Map Distribution, P. O. Box 25286, Federal Center, Denver, CO 80225, for a cost of $6.00 (plus a $1.00 handling charge for orders that total less than $10.00). Prepayment is required; please make checks payable to *Department of Interior–U.S.G.S.*

New Educational Series Report on Earthquake Hazard

The center part of this issue of *Pennsylvania Geology*, which begins on the following page, is a preprinting of the newest Educational Series report of the Pennsylvania Geological Survey, **Earthquake Hazard in Pennsylvania.**[1] Accounts of nearby earthquakes in the United States and Canada have occurred with great frequency in the press in recent months. Most recently, on April 28, 1989, a moderate earthquake, centered near New Madrid, Missouri, was felt in nearby states.

To provide the most up-to-date information on Pennsylvania earthquakes, we are using the central signature of *Pennsylvania Geology* to quickly make this new publication available to the earth science community and concerned citizens. The report, prepared by Charles K. Scharnberger of Millersville University, contains information on how earthquake hazard estimates are calculated. The author concludes that earthquakes pose only a slight hazard in Pennsylvania. The report will also be printed in bulk quantity as a separate booklet (Educational Series 10) and will be provided free to earth science teachers, students, and others who wish to learn more about the earthquake hazard in Pennsylvania. To order additional copies of Educational Series 10, please write to the Pennsylvania Geological Survey, P. O. Box 2357, Harrisburg, PA 17105.

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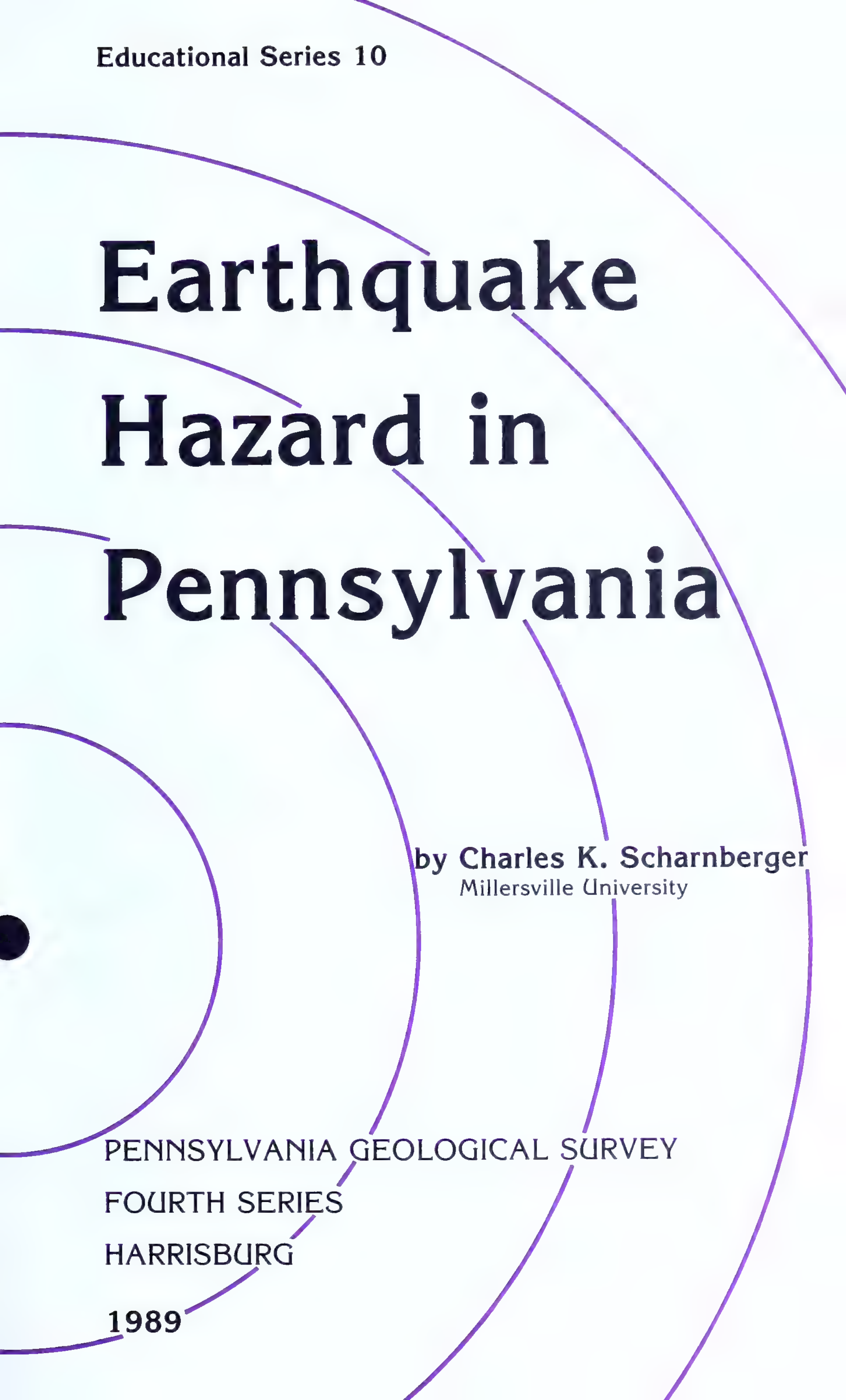
[1] Preprinted from Scharnberger, C. K. (1989), *Earthquake hazard in Pennsylvania*, Pennsylvania Geological Survey, 4th ser., Educational Series 10, 14 p., copyright © 1989 by the Commonwealth of Pennsylvania.



Educational Series 10

Earthquake Hazard in Pennsylvania

by Charles K. Scharnberger
Millersville University

PENNSYLVANIA GEOLOGICAL SURVEY
FOURTH SERIES
HARRISBURG

1989

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Earthquake Hazard in Pennsylvania

by

Charles K. Scharnberger

Introduction

Compared to other states, especially California and Alaska, Pennsylvania is relatively free of earthquake activity. Even considering only the eastern half of North America, Pennsylvania has experienced fewer and milder earthquakes than most other states or Canadian provinces. Nevertheless, earthquakes do occur in our Commonwealth, and Pennsylvania may be subject to the effects of earthquakes that have epicenters located outside our borders. Therefore, it is worth considering how much hazard earthquakes present to Pennsylvanians.

What is an Earthquake?

Earthquakes occur when there is a sudden release of stored energy from a portion of a fault plane within the earth. Faults are fractures in the lithosphere—the rather brittle outer layer of the solid earth. Energy in the form of *strain*, small elastic distortion of the lithosphere, accumulates over a period of time due to *stress* acting on the rock of the lithosphere. The origin of this stress is believed by most geophysicists to be slow convective motion, driven by heat energy, which occurs below the lithosphere in the mantle. One consequence of this slow convection is the fragmentation of the lithosphere into tectonic plates, and the slow movement of these plates relative to each other. Much of our understanding of earthquakes, as well as other geologic phenomena such as volcanic eruptions and mountain-building, is based on this theory of *plate tectonics.*

The rock of the lithosphere can accommodate only so much strain energy. Eventually, the rock must fracture. When this happens, strain is relieved, the stress level drops, some energy is converted into heat, some movement (slip) occurs along the plane of fracture (the fault plane), and some energy is radiated away from the area of fracture in the form of elastic waves—called *seismic waves*—which travel through the earth or along the surface of the earth. The arrival of these seismic waves at a point on the surface causes rapid and complex motions of the ground. This is what we feel as an earthquake. Once a fault has formed as the result of an initial fracture, earthquakes are likely to recur along the same fault, because this plane is now a zone of weakness in the lithosphere.

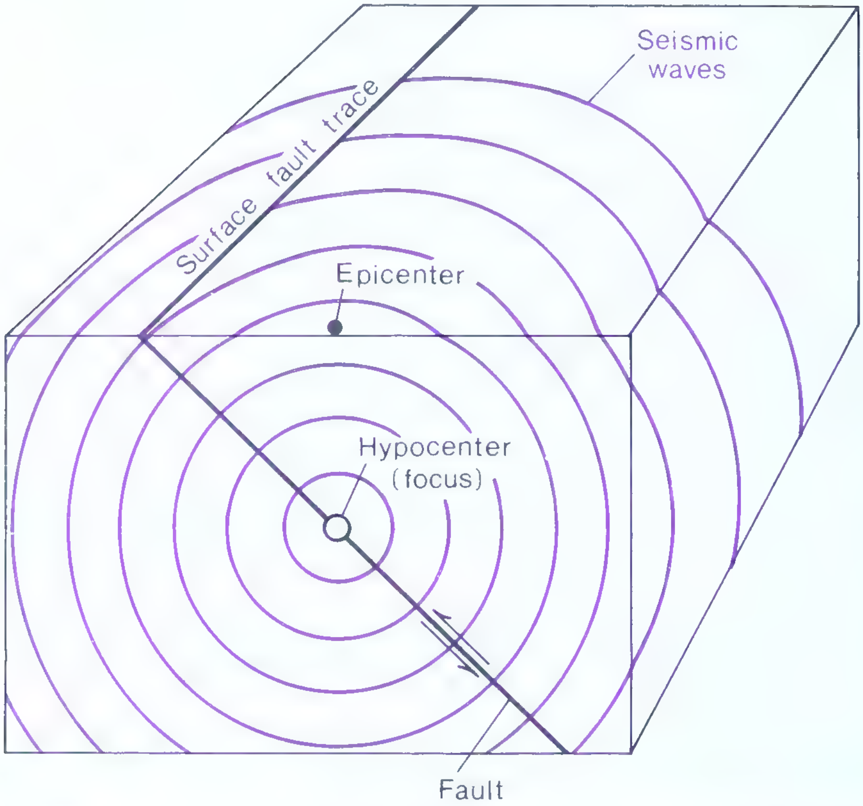

Figure 1. Relationship among fault plane, fault trace on surface of the earth, earthquake hypocenter (focus), epicenter, fault slip (arrows), and seismic waves. (Based on Plummer, C. C., and McGeary, David, *Physical geology*, 4th ed., Figure 16.2, p. 345. Copyright © 1988 by Wm. C. Brown Publishers, Dubuque, Iowa. All rights reserved.)

Figure 1 shows the relationship of a fault plane to the origin point of the seismic waves (called the *hypocenter* or *focus* of the earthquake) and the *epicenter*, the point on the surface of the earth directly above the hypocenter. Note that, unless the attitude of the fault plane is vertical, the epicenter will be located some distance from the trace of the fault along the surface of the earth. In eastern North America, no earthquake in historic time has caused a displacement of the surface along a fault trace.

Earthquakes and Plate Boundaries

The great majority of the earthquakes in the world occur along the boundaries between tectonic plates. The reason for this is not completely clear, but it may be that stress levels are higher along plate boundaries, or that strain energy builds up more rapidly in those areas. Pennsylvania today is far from the nearest plate boundary—the Mid-Atlantic Ridge, some 2,000 miles to the east. However, about 200 million years ago, when the Atlantic Ocean was just beginning to open as the supercontinent Pangaea broke up, the east coast of North America was at a plate boundary, and many faults in eastern North America were formed at that time. Measurements show that the maximum stress in this region now is a compression acting horizontally in approximately an east-west sense. Where 200-million-year-old faults are oriented roughly north-south, they are susceptible to reactivation by the present-day stress field. This seems to be what is happening to cause at least some of the earthquakes felt in eastern North America.

Earthquake Magnitude

Seismic waves are detected and measured by seismographs. The energies of earthquakes are compared on the basis of their magnitudes, a concept first defined in the 1930's by Charles Richter of the California Institute of Technology. Richter wished to have a single number to describe an earthquake, independent of the distance from the epicenter at which the earthquake waves were recorded. The system he devised commonly is called the *Richter Scale*, a term that often leads to the mistaken impression that there is a kind of physical instrument—a scale similar to those used to measure weights—to which the term applies. The numbers of the Richter Scale are logarithms; that is, numbers that express powers of 10. As originally defined by Richter on the basis of California earthquakes recorded locally on a particular type of seismograph, the magnitude represented the maximum amount of ground movement at a distance of 100 kilometers (62 miles) from the epicenter of an earthquake. Each whole number on the scale represented a 10-fold difference in this amplitude of ground motion.

As the concept of magnitude came to be used worldwide and had to be calculated from many different types of seismographs, new ways of defining the magnitude were introduced, so that today several different magnitude numbers might be found for the same earthquake. Thus, magnitudes are useful mostly for comparing earthquakes (the purpose Richter had in mind), rather than for finding the actual energy of an earthquake with more than rough precision.

There is no upper or lower limit to the Richter Scale, but as a matter of historical fact, no magnitude greater than about 9 has ever been calculated for an earthquake. Earthquakes in eastern North America seldom have magnitudes greater than 5.

Earthquake Intensity

Before the development of the Richter Scale, earthquakes were compared on the basis of *intensity*. Today, intensity values are an important supplement to the magnitudes because intensity is a semiquantitative expression of the effects caused by an earthquake. These may be effects on people, on man-made structures, or on natural features of the landscape. Intensities are determined after the earthquake on the basis of field observations made by trained personnel, or from survey forms filled out by persons who experienced the earthquake. The U.S. Geological Survey uses reports sent in by postmasters, and compiles intensity data by postal ZIP code.

Obviously, intensity is not a single number for a particular earthquake, but varies from place to place. Usually, the intensity is greatest in the immediate vicinity of the epicenter and decreases with increasing distance from the epicenter. However, many factors affect intensity; among them are topography, type and thickness of soil, direction from the epicenter relative to regional rock structure, and type of bedrock. The greatest intensities are often caused by landslides induced by the seismic waves rather than by the direct effects of the waves.

In the United States, intensities are expressed in terms of the *Modified Mercalli Scale*. This scale was first proposed in Italy by Giuseppi Mercalli early in this century, and was modified in 1931 by the American seismologists H. O. Wood and F. Neumann (for this reason, it is also called the Wood-Neumann Scale). Table 1 is an abridged version of the Modified Mercalli Scale; Roman numerals usually are used to avoid confusion with earthquake magnitude.

Earthquake Hazard and Earthquake Risk

Although the words "hazard" and "risk" may seem synonymous, there is a distinction to be made between them, at least for natural phenomena. Gere and Shah (1984, p. 112) define "hazards" as "those natural events that threaten life and property." "Risks" are defined as "everything that we have to lose—including both life and property." Thus, in two areas that have similar earthquake histories, the hazard may be approximately equal, but the risk is much greater in the area that is more densely populated. Hazard and risk together determine probability of loss, the factor most relevant to public policy questions. In this paper, only the question of seismic hazard in Pennsylvania is addressed, and no attempt is made to evaluate seismic risk.

Table 1. *The Modified Mercalli Scale of 1931 (Abridged Version)*

I. Not felt except by a very few under especially favorable circumstances.

II. Felt only by a few persons at rest, especially on the upper floors of buildings. Delicately suspended objects may swing.

III. Felt quite noticeably indoors, especially on the upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration is like the passing of a truck. Duration is estimated.

IV. During the day felt indoors by many, outdoors by few. At night some are awakened. Dishes, windows, and doors are disturbed; walls make a creaking sound. Sensation is like a heavy truck striking a building. Standing motor cars are rocked noticeably.

V. Felt by nearly everyone; many are awakened. Some dishes, windows, etc., are broken; a few instances of cracked plaster occur; unstable objects are overturned. Disturbance of trees, poles, and other tall objects is sometimes noticed. Pendulum clocks may stop.

VI. Felt by all; many are frightened and run outdoors. Some heavy furniture is moved; a few instances of fallen plaster or damaged chimneys occur. Damage is slight.

VII. Everybody runs outdoors. Damage is *negligible* in buildings of good design and construction; *slight* to *moderate* in well-built ordinary structures; *considerable* in poorly built or badly designed structures. Some chimneys are broken. Noticed by persons driving motor cars.

VIII. Damage is *slight* in specially designed structures; *considerable* in ordinary substantial buildings, with partial collapse; *great* in poorly built structures. Panel walls are thrown out of frame structures. Chimneys, factory stacks, columns, walls, and monuments fall; heavy furniture is overturned. Sand and mud are ejected from the ground in small amounts. Changes occur in well water. Persons driving motor cars are disturbed.

IX. Damage is *considerable* in specially designed structures; well-designed frame structures are thrown out of plumb; damage is *great* in substantial buildings, with partial collapse. Buildings are shifted off their foundations. Ground is cracked conspicuously. Underground pipes are broken.

X. Some well-built wooden structures are destroyed; most masonry and frame structures are destroyed along with their foundations. Ground is badly cracked. Rails are bent. Considerable landslides occur on river banks and steep slopes. Sand and mud are shifted. Water is splashed (slopped) over banks.

XI. Few, if any, masonry structures remain standing. Bridges are destroyed. Broad fissures occur in the ground. Underground pipelines are completely out of service. Earth slumps and land slips occur in soft ground. Rails are bent greatly.

XII. Damage is total. Waves are seen on the ground surface. Lines of sight and level are distorted. Objects are thrown upward into the air.

Hazard of Earthquakes Having Epicenters Outside Pennsylvania

Historically, large earthquakes have occurred in three regions of eastern North America: (1) the Mississippi Valley, especially near the town of New Madrid, Missouri; (2) the St. Lawrence Valley, especially near the mouth of the St. Lawrence River, where a magnitude 6 earthquake occurred in November 1988; and (3) Charleston, South Carolina.

New Madrid, Missouri

Three great earthquakes struck the vicinity of New Madrid in December 1811, January 1812, and February 1812. Although there were no seismographs to record these events, each earthquake in the series is estimated to have had a magnitude in excess of 7. These earthquakes were felt in western Pennsylvania, but no damage is known to have occurred there (Abdypoor and Bischke, 1982; all other references to the effects of large historic earthquakes in Pennsylvania are from this source). It is unlikely that future New Madrid earthquakes would be any greater than those of 1811–12, so Pennsylvanians probably do not have to worry about a threat from that quarter.

The St. Lawrence Region

One of the largest earthquakes to have occurred in eastern North America since the time of historic records occurred in 1663 and had an epicenter in Quebec, probably not far from that of November 25, 1988. According to reports of French missionaries, the earthquake of February 5, 1663, triggered large rockslides along the banks of the St. Lawrence; the magnitude is estimated to have been about 7. An earthquake on February 28, 1925, in this area was recorded by seismographs, and its magnitude was calculated at 7.0. It was felt with intensity IV in northeastern Pennsylvania. The earthquake of September 4, 1944, although of relatively modest magnitude (5.6), caused serious damage to the towns of Cornwall, Ontario, and Messina, New York. Northwestern Pennsylvania falls within a western extension of the St. Lawrence seismic region; however, historic earthquakes in this part of the region have been less severe than those farther east. The only St. Lawrence earthquake known to have caused damage in Pennsylvania (at Sayre, Bradford County) occurred on August 12, 1929, and had an epicenter near Attica, New York.

Charleston, South Carolina

Charleston was the site of the largest historic earthquake to have occurred along the eastern seaboard. On August 31, 1886, an earthquake with estimated magnitude between 6 and 7 produced intensities as high as X in the vicinity of Charleston. The intensity was IV throughout most of southern and eastern Pennsylvania. Charleston is 600 miles from Philadelphia, so it seems that, as in the case of New Madrid, a recurrence of the great Charleston earthquake would pose little hazard to Pennsylvania.

Other East Coast Areas

Boston, Massachusetts, felt earthquake shocks in 1744, 1755, 1903, and 1925. The largest of these seems to have been the 1755 event, which had an epicenter offshore near Cape Ann. This earthquake was felt strongly in eastern Pennsylvania, and had an intensity around IV or V in Philadelphia. Northeastern Pennsylvania is, at its closest point, about 230 miles from Cape Ann. This is close enough that intensities of VI might be expected in Pennsylvania from a magnitude 7 earthquake.

Southeastern New York and northern New Jersey have been the sites of moderate earthquakes. Perhaps the largest of these was on December 18, 1737, felt with intensity VII in New York City and intensity IV in eastern Pennsylvania. It is impossible to estimate the probability of a magnitude 7 earthquake occurring in northern New Jersey. However, such an earthquake, if it did occur, would almost certainly produce intensities as high as VIII in eastern Pennsylvania.

Hazard of Earthquakes Having Epicenters in Pennsylvania

Seismicity in Pennsylvania

Figure 2 shows the locations of historic epicenters in Pennsylvania; a list of Pennsylvania earthquakes is given in Table 2. The seismic history of Pennsylvania has been poorly known until recently. Sometimes, nonseismic events such as mine collapses have been mistaken for earthquakes. Many historic earthquakes were forgotten until the work of

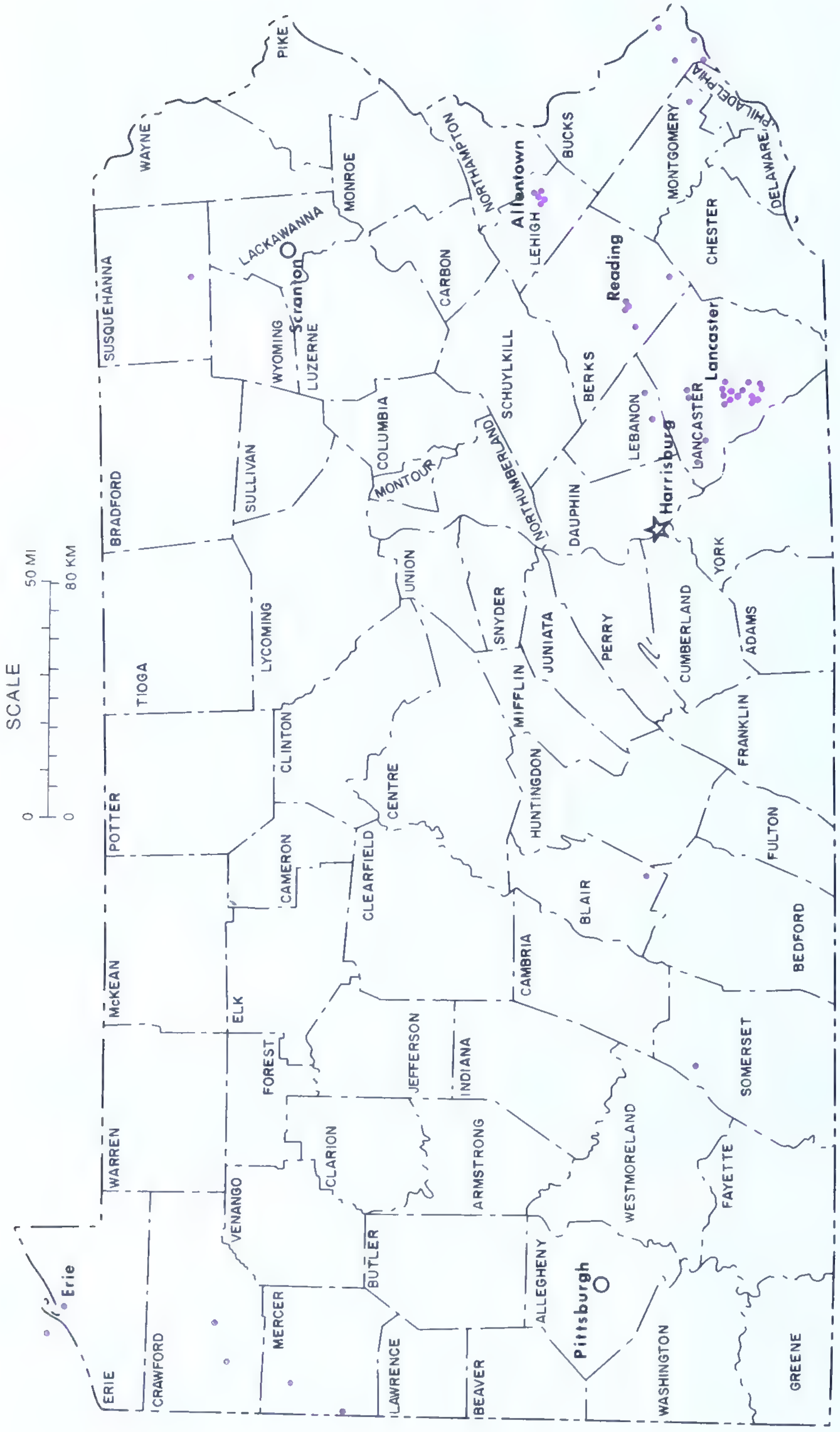

Figure 2. Locations of historic earthquake epicenters in Pennsylvania. Many locations are approximate.

Table 2. *Known Earthquake History of Pennsylvania Through January 1989*

Date (local time)	Location of epicenter	Magnitude[1]	Remarks
LANCASTER SEISMIC ZONE			
1738 or 1739	(?)		
Dec. 17, 1752	(?)	3.6*	
Sept. 1793	(?)		
Jan. 11, 1798	Lancaster(?)		
Nov. 20, 1800	Lititz(?)	4.1*	
Jan. 27, 1801	Lancaster(?)		
Mar. 19, 1818	Lancaster(?)		
Aug. 21, 1820	Mt. Joy(?)	3.4*	
May 4, 1822	Lancaster(?)		
Sept. 5, 1829	Lancaster(?)		
Feb. 5, 1834	Marticville(?)	4.0*	
Sept. 17, 1865	Willow Street(?)		
Nov. 7, 1866	(?)		
Jan. 15, 1885	Schaefferstown		
Mar. 8, 1885	Lancaster(?)		
Sept. 26, 1886	Elizabethtown(?)		
Mar. 8, 1889	Conestoga(?)	4.3*	
May 12, 1964	Cornwall	3.2*	
Dec. 7, 1972	Lititz		
July 16, 1978	Conestoga	3.0	
Oct. 6, 1978	Lancaster	3.1	
Apr. 22, 1984	Marticville	4.1	Foreshock near Mt. Nebo 4 days earlier; many aftershocks
Sept. 19, 1984	Lancaster		
May 2, 1986	Conestoga	2.6	
NORTHWESTERN PENNSYLVANIA			
Sept. 15, 1852	Meadville		
Aug. 17, 1873	Sharon		
Sept. 26, 1921	Erie		
Oct. 29, 1934	Erie		Aftershock near Albion 7 days later
Aug. 26, 1936	Greenville		
Apr. 14, 1985	Conneaut Lake	3.2	
LEHIGH COUNTY			
May 31, 1884	Allentown		
May 31, 1908	Allentown		

Table 2. *(Continued)*

Date (local time)	Location of epicenter	Magnitude[1]	Remarks
	LEHIGH COUNTY *(Continued)*		
June 22, 1928	Allentown		
Nov. 23, 1951	Allentown		
Sept. 14, 1961	Allentown		
	BERKS COUNTY		
May 28, 1906	Geigertown		
June 8, 1937	Reading		
Jan. 7, 1954	Sinking Spring		Beginning of earthquake swarm lasting 1 year
June 25, 1972	Wyomissing		Beginning of earthquake swarm lasting a few days
Aug. 12, 1973	Wyomissing		
	PHILADELPHIA AREA		
Dec. 27, 1961	Bristol		
Mar. 5, 1980	Abington		Foreshock 3 days earlier; aftershock 6 days later
Nov. 14, 1981	Lower Bucks Co.		
Apr. 12, 1982	Cornwells Heights		
May 12, 1982	Lower Bucks Co.		
	BLAIR COUNTY		
July 15, 1938	Clover Creek		
	SOMERSET COUNTY		
Feb. 3, 1982	Jennerstown	2.6	
	SUSQUEHANNA COUNTY		
Aug. 14, 1982	Hop Bottom	2.1	

[1] Asterisk indicates inferred magnitude.

Armbruster and Seeber (1987) brought them to light. The most active part of the state is the Lancaster seismic zone of Lancaster and Lebanon Counties. Next most active is northwestern Pennsylvania, from Erie southward along the Ohio border. Earthquakes are also known from Lehigh, Berks, Montgomery, Bucks, Blair, Somerset, and Susquehanna Counties. Because of the number and magnitude of the earthquakes in the Lancaster seismic zone, that area is examined here in some detail.

Magnitude-Frequency Relationship for the Lancaster Seismic Zone

Gutenberg and Richter (1954) discovered a simple relationship between the magnitudes of earthquakes and the frequency of their occurrence. When one plots on a logarithmic scale the number of earthquakes that have magnitudes equal to or greater than a given value against the magnitude numbers, the points fall on a straight line having negative slope. From the slope of this line, one might predict the number of earthquakes expected to occur within the period of time for which the plot has been made, up to any magnitude cutoff. The result of doing this for earthquakes of the Lancaster seismic zone is shown in Figure 3. In making this plot, the earthquake of September 17, 1865, has been considered as an event having a magnitude of at least 4, based on contemporary newspaper accounts, and the foreshock of the April 22, 1984, earthquake has been included in the count of events having magnitudes of 3 or greater. The magnitudes of many of the early earthquakes in

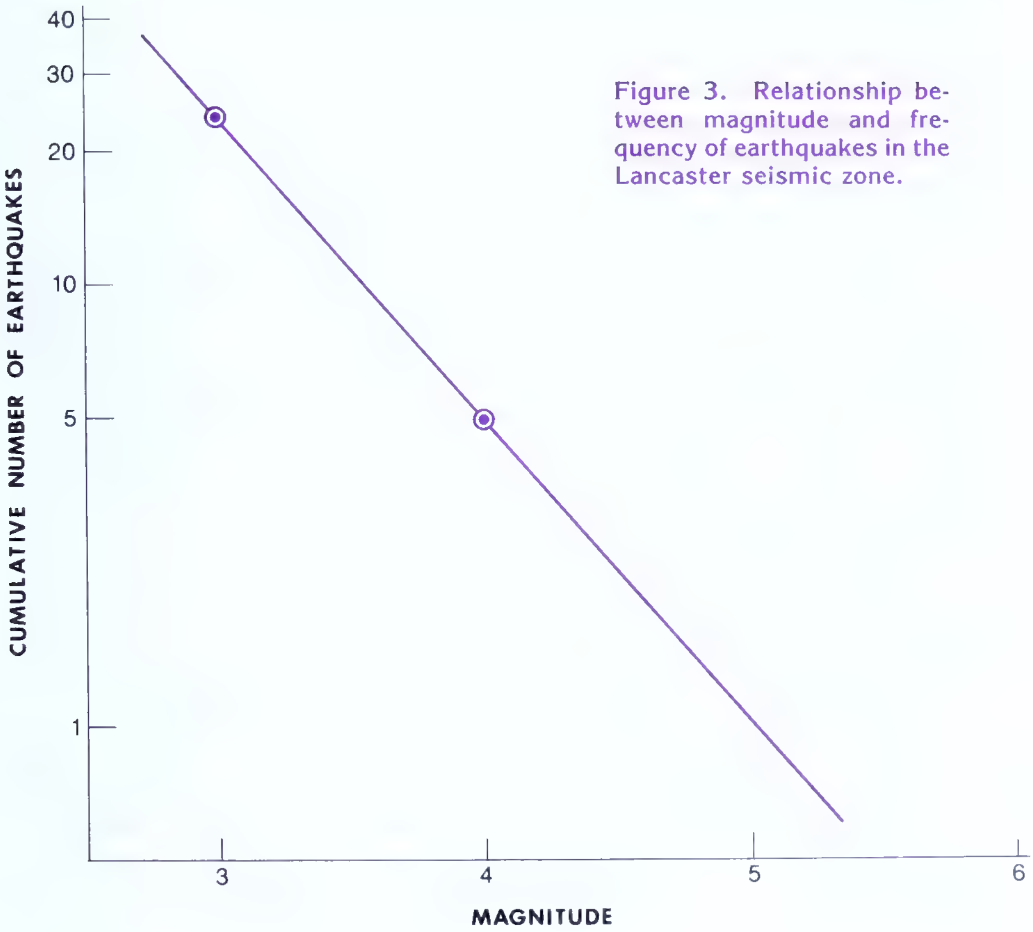

Figure 3. Relationship between magnitude and frequency of earthquakes in the Lancaster seismic zone.

the historic record are not known very precisely, the historical record may not be complete, and the total number of earthquakes is small; therefore, Figure 3 must be interpreted with some caution.

The slope of the line in Figure 3 is − 1.13. Extending this line to magnitude 5, we see that one such event is expected to occur in about 250 years, the length of the historic record. No earthquake of this great a magnitude is known to have occurred in the Lancaster seismic zone, but a count of 0 when the expected count is only 1 does not have a great deal of significance. Based on this analysis, then, it seems possible that an earthquake having a magnitude of around 5 could occur in the Lancaster area.

A Probabilistic Approach

Another way to try to estimate the seismic hazard in the Lancaster seismic zone is to use the probabilistic method applied by Howell (1979) to all of Pennsylvania. Howell's analysis suffered from the fact that much of the historic earthquake record was not known in 1979, and from the inclusion of a number of nonseismic events, particularly the 1954 Wilkes-Barre mine collapse. His method, however, seems worth trying on what probably is a fairly complete record for the Lancaster seismic zone.

Howell's approach was based on the same method used to estimate the likelihood of extreme floods, such as the so-called 100-year or 200-year flood. The essence of the method is to divide the historical record into time intervals of equal length and then to identify the largest earthquake to have occurred in each interval. The usual interval is one year, but because earthquakes are rather rare events, it seems better to use a longer time interval; for the present study, four-year periods were used, beginning in 1730. There are 62 four-year periods in the 258 years from 1730 through 1987. The earthquakes are plotted on probability paper (Figure 4) in order of increasing magnitude and increasing improbability. The improbability of an event is $(1-P)$, where P is the probability. The smallest magnitude used was 2.6; the smaller historical earthquakes for which no magnitude is known were assigned an estimated magnitude of 3.0. Magnitudes for the larger historical events have been taken from Armbruster and Seeber (1987).

As an example, consider the earthquake of 1820, which had an estimated magnitude of 3.4 (Table 2). There are 17 time periods in which earthquakes have occurred. In seven of these, the magnitude of the largest earthquake was greater than or equal to 3.4. From this, we can conclude that the improbability of an earthquake having a magnitude of 3.4 or greater occurring in any four-year period is $(62-7)/62 = 0.89$. This corresponds to a probability of 0.11 (or 11 percent) that such an

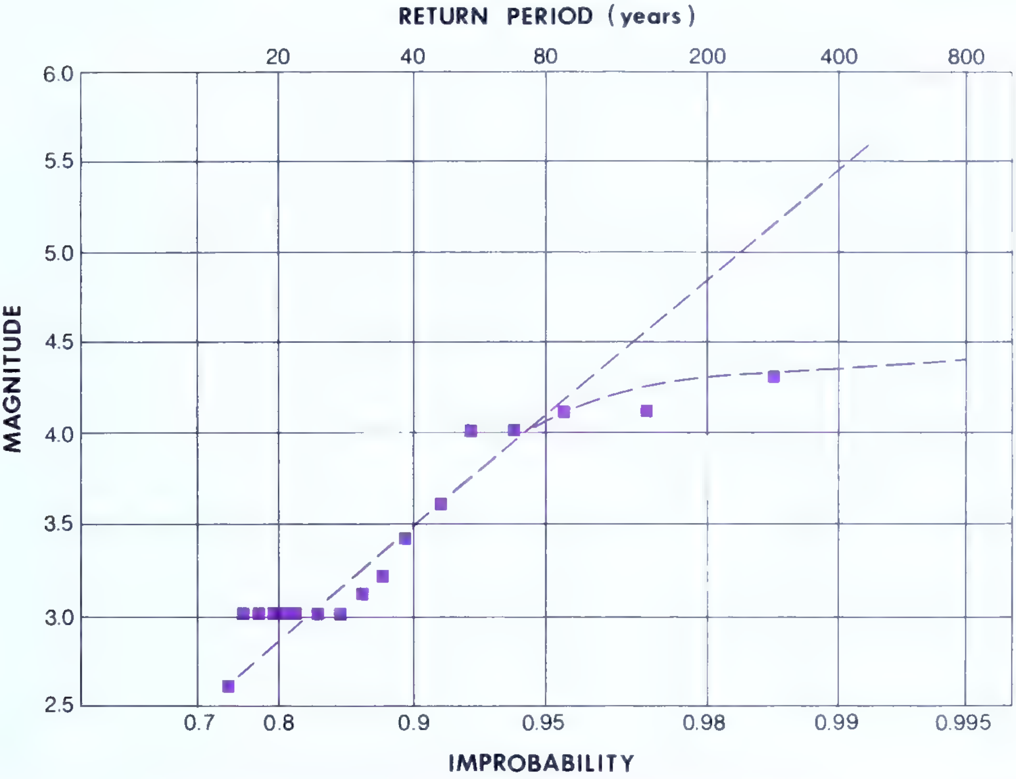

Figure 4. Relationship among magnitude, improbability, and the return period of earthquakes in the Lancaster seismic zone.

earthquake *will* occur. This is approximately 1 chance in 10, and since there are 40 years in 10 four-year periods, we could refer to a magnitude 3.4 event as the "40-year earthquake" for the Lancaster seismic zone. Note, however, that this does not mean that an earthquake of at least that magnitude is certain to occur every 40 years. The probability of the "40-year earthquake" actually occurring in a 40-year period is $(1 - 0.9^{10}) = 0.65$, or 65 percent.

If there is no upper bound to the magnitudes that can occur, then the distribution on probability paper should be a straight line. A fairly good straight-line fit can be made through the first 15 points on Figure 4. The extension of this line suggests that the 200-year earthquake has a magnitude of about 4.8 and the 400-year earthquake has a magnitude of about 5.5 (a 1 percent chance of a magnitude 5.5 earthquake occurring in any 4-year period). The return period for a magnitude 5.0 earthquake is about 250 years, a result consistent with the result obtained from the first method of analysis.

However, considering the remaining two points in Figure 4, we see that the curve through all 17 points deviates significantly from a straight line. This suggests that the magnitudes of earthquakes in the Lancaster seismic zone are not unbounded, but rather have a limit of about 4.5.

Conclusion

Two of the areas that have generated the largest historical earthquakes in eastern North America—New Madrid, Missouri, and Charleston, South Carolina—are too far away for earthquakes having epicenters there to cause damage in Pennsylvania, although earthquakes occurring in those areas that have magnitudes near 7 would be felt in Pennsylvania. Eastern Massachusetts is closer, and a magnitude 7 earthquake there could produce intensity VI effects in northeastern Pennsylvania. Similar intensities might be expected in north-central and northwestern Pennsylvania from earthquakes that have epicenters in the western part of the St. Lawrence zone. The possibility that a magnitude 7 earthquake could occur having an epicenter near New York City cannot be completely discounted, and such an earthquake could produce significant damage (intensity VIII) in eastern Pennsylvania.

Within Pennsylvania, Lancaster, York, Erie, Reading, Allentown, and Philadelphia probably will continue to feel earthquakes generated on local faults. A few earthquakes are likely to occur in other areas, including, perhaps, some that up to now have not been known to be seismic. The largest Pennsylvania earthquakes have been generated in the Lancaster seismic zone, and analysis of the historic record suggests a limit of about 4.5 on the magnitudes of earthquakes that are likely to occur there. This conclusion, however, must be regarded as a very tentative one.

The earth is an extremely complex natural system; even after 200 years of organized geological study, we understand only partly how our planet works. This is true for seismology as much as for any branch of the earth sciences, and the earth may have some seismic surprises in store for us. Thus, the best we can say is this: based on the historic record of earthquakes in eastern North America and on the current state of scientific knowledge, earthquakes pose only a slight hazard in Pennsylvania.

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"Clams Mahantango and *Escargots* to Go," Perry County Style

by Jon D. Inners
Pennsylvania Geological Survey

For more than a hundred years, geologists and paleontologists have recognized the Mahantango Formation of Perry County as a veritable fossil smorgasbord. This Middle Devonian age rock unit underlies a half-dozen zigzag outcrop belts in the eastern two thirds of the county. Throughout this area, innumerable borrow pits, roadcuts, and stream gullies abound in a wide variety of invertebrate fossils. Despite a wealth of good localities, relatively few have been the subject of paleontologic descriptions (see Ellison, 1965, and Inners and Nork, 1983). Because some of the best sites are on private property that is closed to collecting, it is important to publicize localities that are freely open to collectors. One such site known to the author is a borrow pit in the northeastern part of the county.

The site is an active borrow pit near the intersection of U.S. Route 11–15 and Pa. Route 104, three miles northeast of Liverpool in Liverpool Township. It is situated 400 feet west of U.S. Route 11–15 directly behind the former Martin's Motel (Figure 1; 40°36′52″N/76°57′21″W, Millersburg quadrangle). The pit is on the property of Mr. Chester Strawser, R. D. #1, Liverpool, who also owns the Seven Stars collecting site in Juniata County (Hoskins and others, 1983). Please call Mr. Strawser at 717–444–3525 to obtain permission to visit the site.

Exposed in the Strawser pit is medium-dark-gray, massively bedded, bioturbated silty claystone and fissile, silty clay shale belonging to the medial part of the Sherman Ridge Member, the uppermost of several subdivisions of the Mahantango Formation in the lower Juniata and Susquehanna River valleys (Hoskins, 1976). The claystones typically exfoliate into large spheroidal masses that break down into splintery and chippy fragments. About 75 feet of section crops out in the pit, the best exposures being on the south wall (Figure 2). Bedding in the pit strikes N51°E and dips 35 degrees to the southeast.

Invertebrate fossils abound in the Strawser pit. In fact, they are so abundant that nearly every fragment picked from the rubble piles contains a shell or two. The fossils are mainly internal and external molds, but original shell material is not uncommon. The delicate calcitic valves of a tiny chonetid brachiopod (unidentified as to genus and species) are particularly well preserved. Whereas an abundance of bivalves and gastropods is the most distinctive feature of the pit, other invertebrates, including brachiopods, cephalopods, and trilobites are also common.

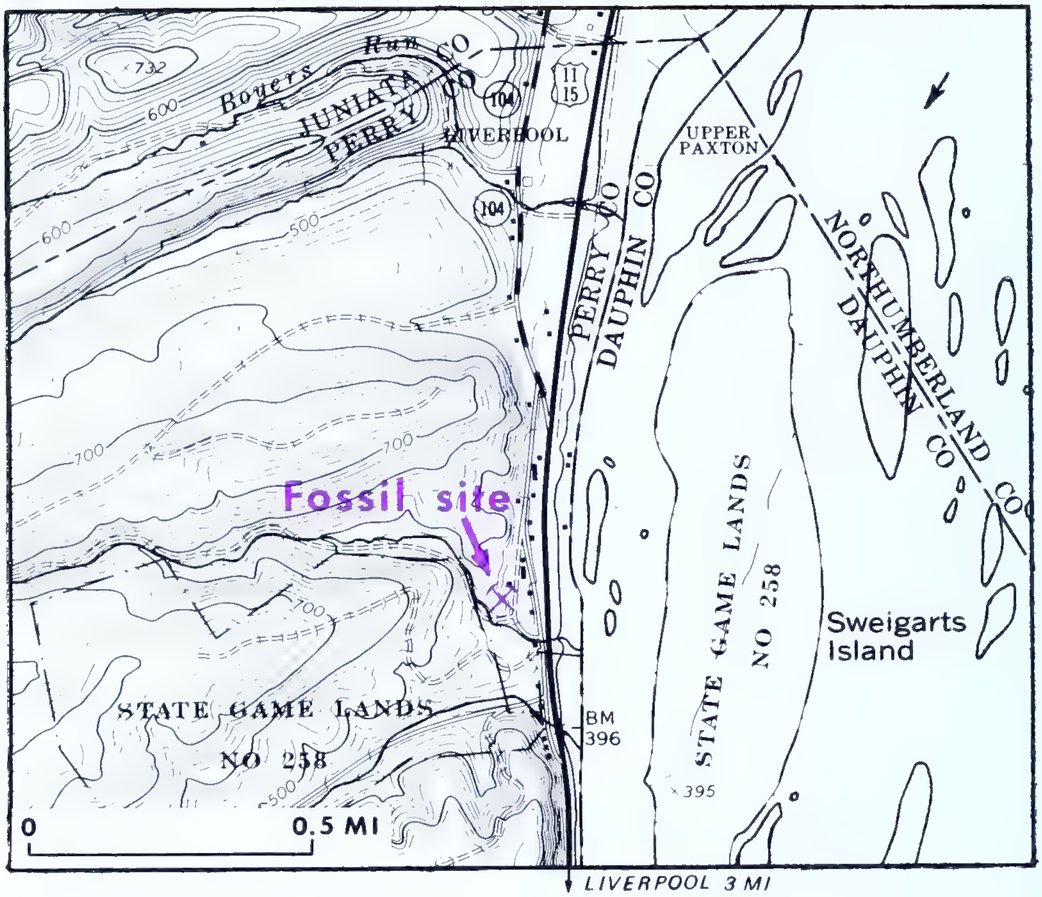

Figure 1. Location map.

Conspicuous by their absence are the many genera of bryozoans that characterize some other sites in the upper Sherman Ridge (Ellison, 1965).

The author collected the following invertebrate fossils at the site (relative abundance: A, abundant; C, common; U, uncommon; and R, rare).

BRACHIOPODS

Devonochonetes scitulus (Hall) R
Leiorhynchus sp. U
Mucrospirifer mucronatus (Conrad) A
Mediospirifer audaculus (Conrad) C

BIVALVES

Nuculoidea sp. C
Nuculites oblongatus (Conrad) C
Goniophora hamiltonensis Hall U
Cypricardella bellastriata (Conrad) C
Paracyclas lirata (Conrad) C
Palaeoneilo constricta (Conrad) U

GASTROPODS

Bembexia sp. A
Small unidentified types C

CEPHALOPODS

Michelinoceras sp. U

TRILOBITES

Greenops (Greenops) boothi var. *calliteles* (Green) C
Phacops rana (Green) C [The new Pennsylvania "State fossil"]

CRINOIDS

Columnals C

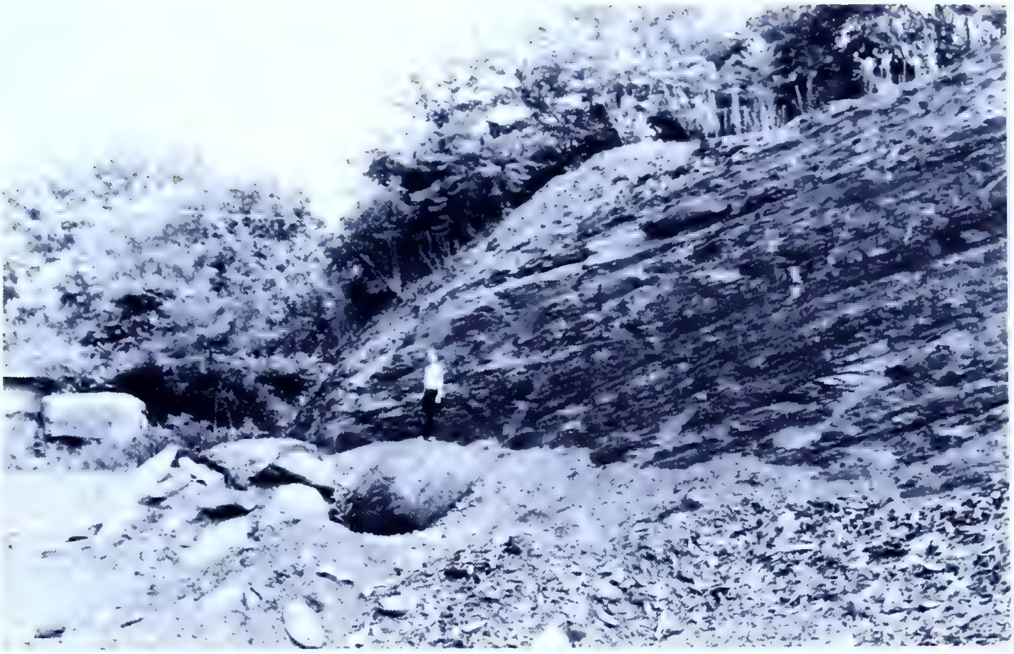

Figure 2. View of the Strawser borrow pit, looking southeast. The large exfoliated mass on which the boy is standing contains enrolled phacopid trilobites.

The shales and claystones exposed in the Strawser borrow pit were originally deposited as fine-grained sediments in a shallow tropical sea that covered much of central and northeastern North America during the late Middle Devonian, about 380 million years ago (Bofinger and Compston, 1967). At that time, central Pennsylvania lay at about 5 degrees south-latitude (Scotese and others, 1979), a position it apparently occupied for at least another 100 million years.

As mapped by Hoskins (1976), the borrow-pit beds occur in the lower part of a sedimentary cycle (100 + feet thick) that coarsens upward from claystone and shale to sandstone—one of many such coarsening-upward cycles in the Mahantango of Perry County and adjacent areas. Kaiser (1972) and Faill and Wells (1974) ascribed this cyclical character to intermittent progradation of a submarine delta. More recent detailed studies, however, suggest that the Mahantango cycles resulted from deposition on storm-tossed shoals and offshore bars at times of fluctuating sea level (Sarwar, 1984; see Brett, 1986).

I thank Dr. Edward Cotter of Bucknell University for supplying me with information on the nondeltaic interpretation of Mahantango cycles.

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Scotese, C. R., Bambach, R. K., Barton, Colleen, and others (1979), *Paleozoic base maps,* Journal of Geology, v. 87, p. 217–277.

NEW PUBLICATIONS OF THE PENNSYLVANIA GEOLOGICAL SURVEY

OIL AND GAS DEVELOPMENTS IN PENNSYLVANIA IN 1987

The latest edition of the Pennsylvania Geological Survey's annual report on developments in the state's oil and gas fields, covering the year 1987, has recently been released. Authors John A. Harper and Cheryl L. Cozart have compiled a report that, not surprisingly, should be useful to those engaged in the serious business of oil and gas exploration and production in Pennsylvania. The report contains many pages of statistical tables, including a massive 40-page table of summarized records of wells that penetrated rocks of at least Middle Devonian age. Stratigraphic data in this report could be of use to geologists beyond those involved in the oil and gas industries. Summaries of current research activities by the Survey's Oil and Gas Geology Division are also included.

What many might find surprising is that any person, geologist or not, who is curious about Pennsylvania's oil and gas industries could find much of interest in this report. The first half of the 80-page volume, in addition to summarizing industrial activity in 1987, contains clear explanations of the kind of activity that took place and, to some extent, how it was accomplished and why it was done. Whether the reader lives in McKean County or Warren County, which between them have over 8,000 producing oil wells, over half the total for the state; in Bradford County, the site of a single producing well that marks the first new oil-field discovery in Pennsylvania in over 20 years (Mark Resources #1 in the Brace Creek field, which produced 174 barrels from the Lock Haven Formation in 1987); or in southeastern Pennsylvania, where there is no reported oil or gas production, but where several test holes have been drilled in recent years, this book can provide interesting insights into an industry that, although declining following a boom in the early 1980's, yielded production worth more than $424 million in 1987.

Progress Report 201, **Oil and Gas Developments in Pennsylvania in 1987**, is available for $2.65, plus 16¢ sales tax if shipped to an address in Pennsylvania, by writing to State Book Store, P. O. Box 1365, Harrisburg, PA 17105. Prepayment is required; please make your check or money order payable to *Commonwealth of Pennsylvania*.

WATER RESOURCES OF GREENE COUNTY

The Pennsylvania Geological Survey is pleased to announce the publication of Water Resource Report 63, **Water Resources and the Effects of Coal Mining, Greene County, Pennsylvania**. The report is the product of a joint county-state-federal project, and was written by U.S. Geological Survey personnel Jeffrey D. Stoner, Donald R. Williams, Theodore F. Buckwalter, John K. Felbinger, and Kenn L. Pattison. The geologic map and cross section were compiled by Pennsylvania Geological Survey staff geologist Clifford H. Dodge.

About 20 percent of the minable bituminous coal reserves in Pennsylvania underlie Greene County. Most of the coal remains in the western part of the county, which has not yet been extensively mined. Concern for the potential effects of future coal subsurface and surface mining on water resources is the central issue of this report.

Topics included in the new publication are the hydrogeologic framework of the county, the hydrologic setting, the groundwater system, the surface water, and the hydrologic effects of coal mining on groundwater and surface water. A full-color geologic map (scale 1:50,000) containing structure contours and well and spring locations is included.

Well yields in the Pennsylvanian- and Permian-age rocks that underlie the county are typically low (less than 4 gallons per minute), and most groundwater circulation is at shallow depths. From these and other data, the authors conclude that only in about 5 percent of the unmined part of the county should mining of the Pittsburgh coal reduce or deplete the yield of wells less than 150 feet deep, or cause significant depletion of streamflow, unless vertical fracture zones or fractures caused by collapsed mine workings effectively connect shallow aquifers to a deep mine.

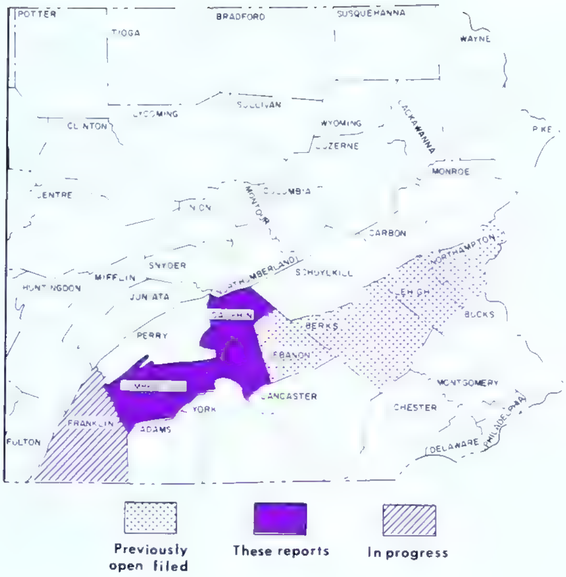
This report will be of interest to anyone involved in obtaining, managing, or protecting water resources in Greene County. By extrapolation, the conclusions can be utilized in other areas of Pennsylvania where mining occurs. A similar report is being prepared on Washington County.

Copies of the report may be ordered from the State Book Store, P. O. Box 1365, Harrisburg, PA 17105; the price is $16.80 (plus $1.01 sales tax if shipped to an address in Pennsylvania). Prepayment is required; please make checks payable to *Commonwealth of Pennsylvania*.

OPEN-FILE REPORTS ON SINKHOLES AND KARST-RELATED FEATURES IN DAUPHIN AND CUMBERLAND COUNTIES

Two new editions of the open-file reports on sinkholes have recently been released by the Pennsylvania Geological Survey. Prepared by staff geologist William E. Kochanov, the reports contain an inventory of sinkholes, closed depressions, and sinkhole-prone areas in Dauphin and Cumberland Counties, compiled on U.S. Geological Survey 7.5-minute quadrangles. The reports also include geologic contacts of carbonate bedrock units, bedding orientations and joint measurements in the carbonate units, cave entrances, and surface mines. This information was obtained through stereoscopic aerial photography examination, field investigations, and contacts with local residents and municipal officials. By using a series of photographs dating back to 1948, the author was able to show sinkholes and karst features that may cause problems for future land use, but that are no longer visible by field investigation or examination of recent aerial photographs.

The two new open-file reports provide a data base that may be used as a starting point for any environmental investigation done by county and township officials, planners, and consultants. Because of the sometimes catastrophic nature of sinkholes, these reports will also be of interest to homeowners and home buyers. Educators will find them useful for classroom or field trip guides. By seeing the patterns of karst fea-



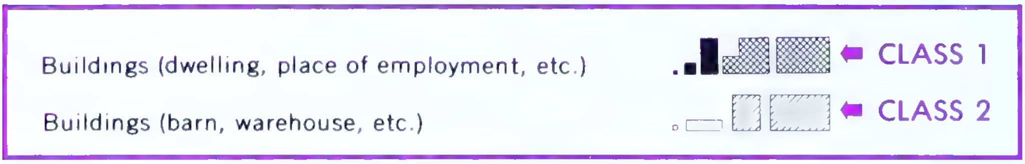
tures and sinkholes plotted on a geologic base map, one is able to gain a general understanding of the carbonate geology and the nature of sinkhole occurrences.

To obtain copies of Open-File Report 89–01, **Sinkholes and Karst-Related Features of Dauphin County, Pennsylvania**, and Open-File Report 89–02, **Sinkholes and Karst-Related Features of Cumberland County, Pennsylvania**, write to the Pennsylvania Geological Survey, P. O. Box 2357, Harrisburg, PA 17105. The price of the Dauphin County report is $12.50 plus 75¢ state sales tax for Pennsylvania residents; the price of the Cumberland County report is $25.00 plus $1.50 state sales tax. Checks must accompany the order and should be made payable to *Commonwealth of Pennsylvania*. The reports may be examined by contacting William Kochanov and visiting the Pennsylvania Geological Survey offices in the Executive House, 101 South Second Street, Harrisburg.

COMMENTS REQUESTED ON USGS PLANS FOR A SYMBOL CHANGE ON TOPOGRAPHIC MAPS

The National Mapping Division (NMD) of the U.S. Geological Survey (USGS) is planning to combine cartographic symbols that presently define two classes of buildings on standard topographic quadrangle maps. At present, the NMD map symbol policy requires use of two distinct symbols for Class 1 and Class 2 structures. Class 1 buildings are structures intended primarily for housing human activities and include residences, hotels, churches, schools, shops, most public and commercial buildings, factories, service stations, and others of similar character.

Class 1 symbols are solid black or are outlined in black and contain a crosshatch pattern (see illustration). Class 2 buildings are structures not intended primarily for housing human activities and include warehouses, barns, greenhouses, sheds, and others constructed to house machinery or animals, or for storage. Class 2 symbols are outlined in black and are either open or contain diagonal line patterns.


Buildings (dwelling, place of employment, etc.)
CLASS 1
Buildings (barn, warehouse, etc.)
CLASS 2

Comments are requested by the USGS to determine the use of building class information as currently depicted on standard topographic quadrangle maps, and the impact of eliminating building class distinctions.

In the past, classification of Classes 1 and 2 was based on information acquired during field survey work. As NMD mapping procedures are changed to make maximum use of high-resolution photography, supplemented with additional cartographic source materials and reduced field survey operations, this information will no longer be readily available.

In addition, provisional edition topographic maps (P–maps) and photorevised maps ("purple" revisions) have been published since 1981 with no distinction between classes of buildings, except for schools, churches, and other landmark buildings, which have been shown as on standard-edition maps. No objections have been raised by map users over the lack of building classification on these two types of maps.

Based on the fact that apparently no use is being made of the distinction between Class 1 and Class 2 buildings, and the desire to expedite mapping operations, the NMD is considering the elimination of the classification of most buildings. However, churches, schools, and landmark buildings will continue to be symbolized and/or labeled according to current standards.

If you have a definite need for the distinction of Class 1 and Class 2 buildings as currently shown on standard-edition topographic maps, please submit a brief description of your application to the USGS. In addition, please describe how you have obtained this information where it has been lacking on provisional edition and photorevised maps. The USGS would also appreciate knowing if you do not have any application for the present classification.

For further information, write or call William J. Jones, Chief, Office of Technical Management, National Mapping Division, 510 National Center, Reston, VA 22092, telephone 703–648–4566.

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FOR
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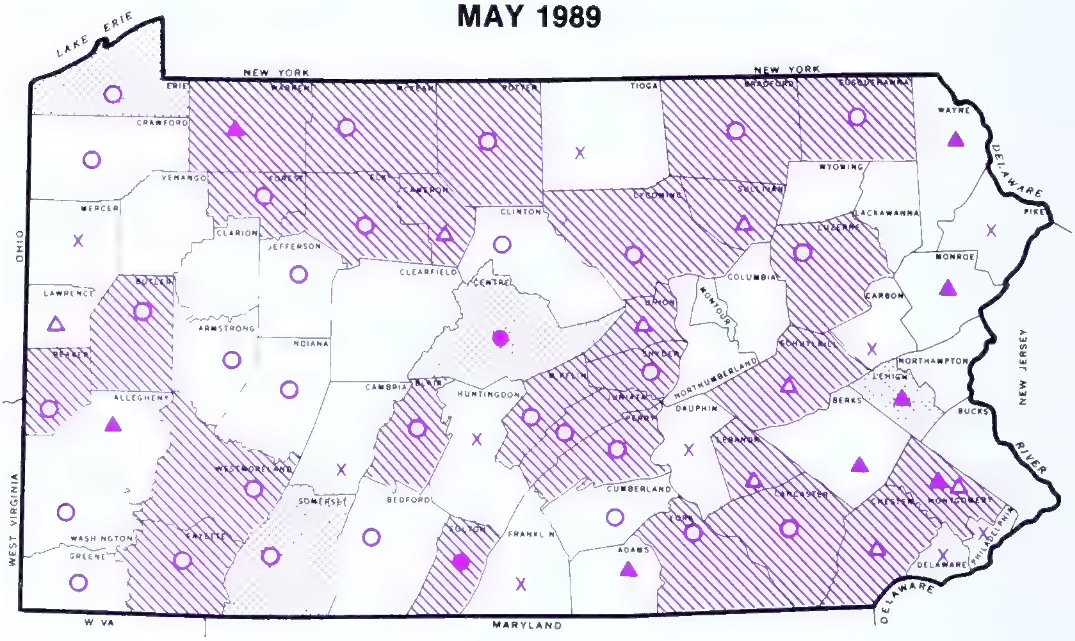

EXPLANATION

○ Above last year · ● Below last year
Observation well

△ Above last year · ▲ Below last year
Observation well equipped with data-collection platform

x No data

▨ High

☐ Normal range

░ Low

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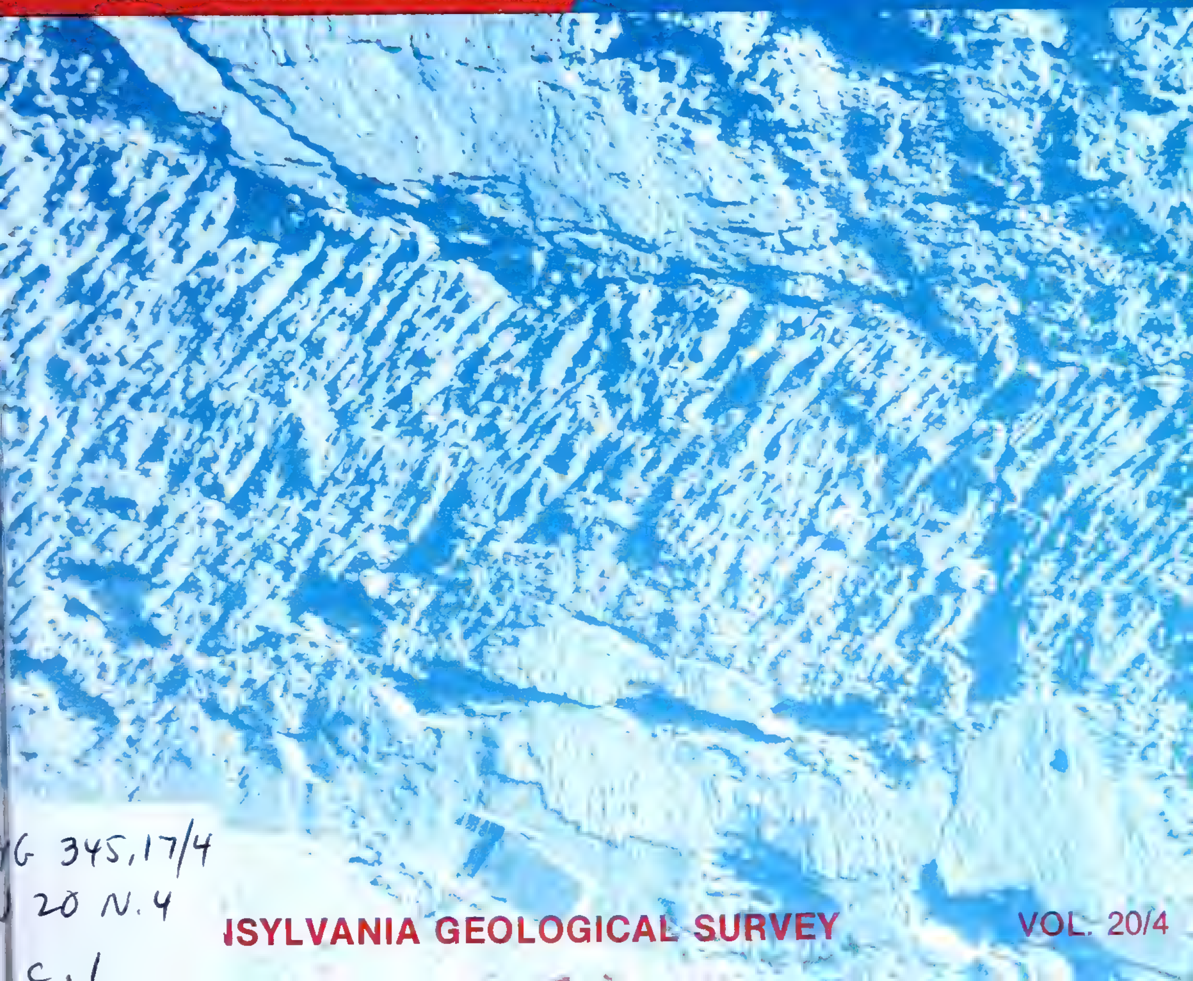

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ISYLVANIA GEOLOGICAL SURVEY

VOL. 20/4

COMMONWEALTH OF PENNSYLVANIA
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ON THE COVER: Pinnate (feather) fractures in siltstone of the Middle Devonian Mahantango Formation, along U.S. Route 22 in Huntingdon. Bedding dips gently to the right, although this is not evident in the photograph. The face of the exposure is a large planar fracture, a master fracture that pervades much of the outcrop. The set of closely spaced pinnate fractures is at an angle of 25 degrees to the master fracture. The notebook in the lower center is 21 cm long. Photograph by R. T. Faill.

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NOV 13 1989

Geology, Art, and Vandalism

Recently, the Geological Society of America published Special Paper 225, *The Art of Geology*. The colorful images of worldwide and world-class geologic features in this volume would grace any coffee table and would be appreciated by anyone who values the beauty of nature. These images illustrate both the art appreciated by all and the geology understood only by the trained viewer. Thus geologic art is doubly valued.

Pennsylvania is not represented in *The Art of Geology*. Yet our Commonwealth possesses much great geologic art of world-class stature. At the recent meeting of the International Geological Congress, 49 images of Pennsylvania geology were one of the main focuses of a large display seen by over 2,000 visitors. These photographs will be on display at the 1989 meeting of the Field Conference of Pennsylvania Geologists and the 1990 meeting of the Northeastern Section of the Geological Society of America. I hope that you will be able to see these exhibits. They include photographs that are the serendipitous result of such research into Pennsylvania's geology as is listed in this issue.

There is, however, a danger in portraying the art of geology, particularly of objects that are collectible. Vandalism (geovandalism) is taking its toll of geological features. Recently, mendacity and greed were exhibited by vandals who, using excavating equipment, removed footprints of Mesozoic dinosaurs from a site near Allentown. At many localities in Pennsylvania, holes have been drilled into rocks to extract specimens for magnetic analyses. These cores have permanently disfigured outcrops that otherwise are sometimes excellent examples of geologic art. The amount of outcrop defaced with spray-painted names and obscenities is legion.

Both geological researchers and collectors must recognize that an outcrop best used for teaching or of unique artistic value, once destroyed, is lost to immediate and future generations. Thus, painting markers on rocks with nearly nondegradable pigment is both objectionable and egotistical.

We need to preserve our geologic art and our outcrops used for teaching. We need to teach our students that soon they will see these with eyes and understanding that only a geologist possesses. All of us have an obligation to preserve our geologic art for others to enjoy.

Donald M Hoskins

Donald M. Hoskins
State Geologist

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GEOLOGICAL RESEARCH IN PENNSYLVANIA
1989

Introduction

This publication, the thirty-second annual report in its series, contains a listing of all known current geological research in Pennsylvania and all known reports published during the past year pertaining to Pennsylvania geology. Because of the large number of projects reported to us, we editorially condense the descriptions to fit available space.

We have requested that each person estimate an anticipated completion date (ACD) for each project. The anticipated completion date is the author's estimate of the date when the project will be finished; additional time should be allowed for publication of the report.

If you wish to obtain more information on a project described herein, please write directly to the author; most of these projects will not be published by the Pennsylvania Geological Survey inasmuch as most are not Survey-sponsored projects.

The listings are grouped into major categories of research to facilitate your search for information on a particular subject. As with all compilations, there may be omissions; this is unintentional.

Additional copies of this report may be obtained by writing to the Pennsylvania Geological Survey, P. O. Box 2357, Harrisburg, PA 17105.

AREAL GEOLOGY

T. M. BERG, Ohio Geol. Survey, and C. M. DODGE and J. D. INNERS, Pa. Geol. Survey. **Map 61, Atlas of Preliminary Geologic Quadrangle Maps of Pennsylvania** (2nd ed). The popular "Map 61 Atlas" is being revised to include all quadrangles of Pennsylvania, and many corrections, additions, and changes are being included. The new edition will provide users with a single, desktop source for all of the bedrock geology of the Commonwealth. ACD: 1991.

T. M. BERG, Ohio Geol. Survey, M. E. MOORE, Pa. Geol. Survey, and M. L. O'NEAL, C. B. CUBBISON, JACQUELINE LUNDY, and J. B. LESSMAN (all student interns, Pa. Geol. Survey). **Geologic Map of Warren County.** This map is being prepared for the Warren County groundwater report, a cooperative project of the Pennsylvania Geological Survey and the U.S. Geological Survey, Water Resources Division. ACD: 1989.

ALAN DAVIS and ETUAN ZHANG, Pa. State Univ. **Causes of Regional Coal Rank Patterns** [western Pa.]. ACD: Dec. 1989.

J. B. EPSTEIN and P. T. LYTTLE, U.S. Geol. Survey, and G. G. LASH, State Univ. of N. Y. at Fredonia. **Geologic Map of the New Tripoli 7.5-Minute Quadrangle.** Mapping of bedrock and surficial deposits and structural geology in the Hamburg klippe, Shochary Ridge sequence, Martinsburg Formation, and Silurian-Devonian rocks of the Ridge and Valley province. ACD: Dec. 1989.

R. T. FAILL, Pa. Geol. Survey. **Geological Investigations in the Pennsylvania Piedmont: Susquehanna River Transect.** Detailed examination of the Peters Creek, Peach Bottom, and Cardiff Formations exposed along the Susquehanna River (east bank) between Drumore and Peach Bottom and evaluation of the Peach Bottom structure as a cryptic suture. ACD: July 1989.

D. B. MacLACHLAN, Pa. Geol. Survey. **Geology of the Freeburg Quadrangle, Snyder County.** Mapping of Tuscarora-to-Catskill section and pre-Wisconsinan glacial and loess deposits, predominantly on the plunging nose of Shade Mountain. The area contains some exposures of the Ridgeley Sandstone and Tully Limestone near the limits of their respective ranges. ACD: 1989.

D. B. MacLACHLAN, Pa. Geol. Survey. **Lower Paleozoic Rocks of Platformal to Marginal Facies in the Pennsylvania Piedmont.** The project, which will include a stratigraphic study and remapping of rocks primarily in Chester and Montgomery Counties, is in the reconnaissance phase, and a site for initial detailed work has not been established.

L. B. PLATT and J. J. SCHAEFER, Bryn Mawr Coll. **Geology Around Little Mountain, Lebanon County.** A continuing project to determine stratigraphy and structure in the Lebanon County part of the Hamburg klippe and related rocks. ACD: May 1989.

W. D. SEVON, Pa. Geol. Survey. **Surficial Geology of the Conestoga, Holtwood, Quarryville, and Wakefield Quadrangles, Lancaster and York Counties.** ACD: 1990.

E. R. SLUCHER, Ohio Geol. Survey. **Bedrock Geology of the East Liverpool North 7.5-Minute Quadrangle, Ohio-Pennsylvania-West Virginia.** ACD: Mid-1989.

E. R. SLUCHER and GLENN E. LARSEN, Ohio Geol. Survey. **Bedrock Geology of the East Palestine 7.5-Minute Quadrangle, Ohio-Pennsylvania.** ACD: Mid-1989.

D. W. VALENTINO, Pa. Geol. Survey. **Geological Investigations in the Pennsylvania Piedmont: Susquehanna River Transect.** Detailed examination of the Wissahickon Schist, Conestoga Formation, and Peters Creek Formation along the Susquehanna River between Washington Boro and Drumore, Lancaster County. The Tucquan-Mine Ridge structure is a possible transpressional antiform. ACD: June 1989.

S. W. BERKHEISER, JR., and R. C. SMITH, II, Pa. Geol. Survey. **Additional Occurrences of Specialty-Use Silica in Pennsylvania.** The purpose of the investigation is to identify and characterize Cambrian-age clastic resources within the South Mountain area of Adams, Cumberland, and Franklin Counties. Additional data concerning the thickness and quality of selected quartz veins and a few other sandstones will also be included. A core hole drilled during the past year penetrated about 700 feet of clastics in Adams County. Chemical analyses will be reported. ACD: Late 1989-early 1990.

S. W. BERKHEISER, JR., and R. C. SMITH, II, Pa. Geol. Survey. **Mineral Fillers of the Piedmont Physiographic Province of Pennsylvania.** Reconnaissance investigations of potential mica, talc, silica, and carbonate mineral fillers in the Piedmont province. These studies are preliminary in nature and support anticipated new mapping programs in the region. ACD: Ongoing.

S. W. BERKHEISER, JR., and R. C. SMITH, II, Pa. Geol. Survey. **Reconnaissance Investigations and Analyses of High-Purity Carbonate Resources in Pennsylvania.** Preliminary reconnaissance investigations with the object of updating and identifying new high-purity carbonate resources for use in the acid-mitigation fields. The Ridge and Valley physiographic province contains numerous carbonate sequences of Cambrian through Devonian age. ACD: Ongoing.

C. H. DODGE, Pa. Geol. Survey. **Coal Resources of Elk County—Part 1, Coal Crop Lines, Mined-Out Areas, and Structure Contours.** Detailed geologic mapping of the coal-bearing strata (Pottsville, Allegheny, and Glenshaw Formations) of Pennsylvanian age. Emphasis is on the major coal-bearing structural basins. A series of maps will be prepared including (1) separate crop-line maps for each principal coal seam showing areas of strip and deep mining, and (2) composite maps showing the crop lines of major and minor coals, as well as structure contours and fold axes. ACD: 1992.

A. D. GLOVER, Pa. Geol. Survey. **Coal Resources of Jefferson County—Part 1, Coal Crop Lines, Mined-Out Areas, and Structure Contours.** Published and unpublished data will be used to prepare a series of maps including (1) separate crop-line maps for each principal coal seam showing areas of strip and deep mining, and (2) composite maps showing the crop lines of all principal coals, as well as structure contours and fold axes. ACD: 1992.

A. D. GLOVER, Pa. Geol. Survey, and W. A. BRAGONIER, Rochester and Pittsburgh Coal Co. **Coal Resources of Armstrong County—Part 1, Coal Crop Lines, Mined-Out Areas, and Structure Contours.** Published and unpublished data will be used to prepare a series of maps including (1) separate crop-line maps for each principal coal seam showing areas of strip and deep mining, and (2) composite maps showing the crop lines of all principal coals, as well as structure contours and fold axes. ACD: 1990.

A. D. GLOVER, Pa. Geol. Survey, and W. A. BRAGONIER, Rochester and Pittsburgh Coal Co. **Coal Resources of Indiana County—Part 1, Coal Crop Lines, Mined-Out Areas, and Structure Contours.** Published and unpublished data will be used to prepare a series of maps including (1) separate crop-line maps for each principal coal seam showing areas of strip and deep mining, and (2) composite maps showing the crop lines of all principal coals, as well as structure contours and fold axes. ACD: 1989.

J. D. INNERS, Pa. Geol. Survey. **Geology of Anthracite in the Hazleton Quadrangle, Luzerne, Schuylkill, and Carbon Counties.** Project mainly involves preparation of 1:12,000-scale coal-bed outcrop and structure-contour (Buck Mountain/Mammoth seams) maps of the anthracite basins in the Hazleton area of the Eastern Middle Anthracite field. ACD: July 1990.

L. J. LENTZ, Pa. Geol. Survey. **Coal Resources of Greene County—Part 2, Overburden Thickness, Coal Quality, and Coal-Reserve Estimates.** Computer compilation and manipulation of coal data for Greene County continues. Data base includes point and line data, stratigraphic data, and chemical data in files managed by the U.S. Geological Survey in Reston, Virginia. ACD: Ongoing.

L. J. LENTZ, Pa. Geol. Survey. **Coal Resources of Washington County—Part 2, Overburden Thickness, Coal Quality, and Coal-Reserve Estimates.** Computer compilation and manipulation of coal data for Washington County continues with the entry of new records and the updating of others. Data base includes point and line data, stratigraphic data, and chemical data in files managed by the U.S. Geological Survey in Reston, Virginia. ACD: Ongoing.

A. K. MARKOWSKI, Pa. Geol. Survey. **Preliminary Feasibility Study of the Coal-Bed Methane Resource in Pennsylvania.** Data were obtained from exploratory coreholes in Armstrong, Cambria, Somerset, and Greene Counties, from pre-mining degasification holes, and from methane-recovery test projects. Variations in gas content with other geologic controls are used in assessing economic viability. ACD: 1989.

R. F. MAST, G. L. DOLTON, R. RYDER, J. B. ROEN, W. DE WITT, and others, U.S. Geol. Survey. **National Petroleum Assessment—Appalachian Basin.** Petroleum geology and assessment of Appalachian basin; part of a study of the entire United States. ACD: Ongoing.

G. R. ROBINSON, Project Chief, U.S. Geol. Survey. **Metallogeny of the Early Mesozoic Basins of the Eastern United States.** Field work and other geologic studies in the Newark basin of New Jersey and Pennsylvania, the narrow neck area between the Newark and Gettysburg basin of Pennsylvania, and the Culpeper basin of Virginia are continuing. We are in the process of bringing to completion many of the ongoing topical studies. Preliminary versions of a suite of maps covering all of the exposed early Mesozoic basins of the eastern United States should be ready for review in the near future.

J. B. ROEN, U.S. Geol. Survey. **Petroleum Geology Research, Appalachian Basin.** Petroleum geology and geochemistry of the Ordovician and Devonian black shales of the Appalachian basin. ACD: Ongoing.

J. R. SHAULIS, Pa. Geol. Survey. **Coal Resources of Somerset County—Part 1, Coal Crop Lines, Mined-Out Areas, and Structure Contours.** Published and unpublished data will be used to prepare a series of maps including (1) separate crop-line maps for each principal coal seam showing areas of strip and deep mining, and (2) composite maps showing the crop lines of all principal coals, as well as structure contours and fold axes. ACD: 1990.

A. K. SINHA, Va. Polytechnic Inst., and R. C. SMITH, II, S. W. BERKHEISER, JR., and J. H. BARNES, Pa. Geol. Survey. **Trace-Element Content of Some Pre-Mesozoic Basaltic Rocks in Pennsylvania.** A test will be made to determine if the trace-element content of pre-Mesozoic basalts can be used to establish possible mineralization and affinities.

V. W. SKEMA, Pa. Geol. Survey. **Coal Resources of Clearfield County—Part 1, Coal Crop Lines, Mined-Out Areas, and Structure Contours.** Detailed geologic mapping of the coal-bearing strata of Pennsylvanian age. Emphasis is on the major coal-bearing structural basins. A series of maps will be prepared including (1) separate crop-line maps for each principal coal seam showing areas of strip and deep mining, and (2) composite maps showing the crop lines of major and minor coals, as well as structure contours and fold axes.

R. C. SMITH, II, and S. W. BERKHEISER, JR., Pa. Geol. Survey. **Precious Metals Reconnaissance in Southeastern Pennsylvania.** We are conducting whole-rock and stream heavy-mineral reconnaissance to determine preferred methods for the area. ACD: Ongoing.

ENVIRONMENTAL GEOLOGY

WOLFGANG BAUM, Pittsburgh Mineral and Environmental Technology, Inc. **Mineralogical Characterization Methods for Soil Contaminations and Waste Rock/Process Tailings from Various Mining Operations.** ACD: 1989.

F. J. BRENNER, Grove City Coll., J. J. MONDOK and ROBERT McDONALD, Mercer Co. Conservation Dist., and RICHARD STEINER, Univ. of Akron. **Role of Ground and Surface Water Flow in Nonpoint-Source Pollution.** Investigation of the relationship between groundwater and surface-water flows and nonpoint-source pollution parameters. Study is concerned with the effect of soil type, land use, and subsurface and overland flow on water quality in an agricultural watershed. ACD: 1992.

F. J. BRENNER, Grove City Coll., and M. P. STEINER and T. M. SHAW, Univ. of Akron. **Relationship Between Surface Coal-Mine Lakes and Surrounding Water Wells.** Investigation of the relationship between water chemistry of surface coal-mine lakes and the chemistry of surrounding water wells. The object is to determine if a knowledge of the water chemistry of wells enables a prediction of water chemistry of surface-mine lakes after mining. ACD: 1990.

P. H. DOUGHERTY, Kutztown Univ. **Utilization of Karst Concepts in Zoning Ordinances** [Lower Macungie Twp., Lehigh Co.]. A survey of Pennsylvania municipalities has shown a paucity of zoning ordinances that include karst subsidence precautions. The aim of this project is to create a model ordinance for use by Lower Macungie Township and other similar localities. ACD: 1989–90.

P. H. DOUGHERTY, Kutztown Univ., and MICHAEL PERLOW, VFC, Inc. **The Macungie Sinkhole, Lehigh Valley: Cause and Repair.** An ongoing program to determine the occurrence and cause of karst subsidence in the Lehigh Valley. This particular study documented the history of an 81-foot-wide by 41-foot-deep sinkhole that formed in Macungie.

W. E. KOCHANOV, Pa. Geol. Survey. **Karst, Sinkholes, and Engineering Considerations in the Carbonate Terrains of Pennsylvania.** ACD: Spring 1990.

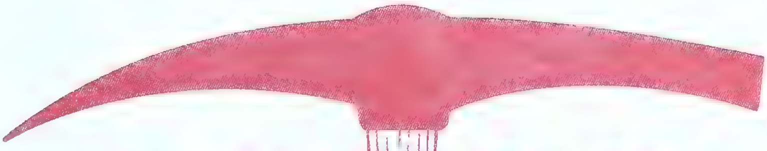
W. E. KOCHANOV, Pa. Geol. Survey. **Sinkholes and Karst-Related Features of Franklin County.** ACD: Fall 1989.

W. E. KOCHANOV, Pa. Geol. Survey. **Sinkholes and Karst-Related Features of Lancaster County.** ACD: Fall 1989.

A. W. ROSE, JOHN WASHINGTON, DANIEL GREEMAN, EDWARD CIOLKOSZ, and WILLIAM JESTER, Pa. State Univ. **Generation and Mobility of Radon in Soils** [eastern U.S.]. The abundance and behavior of radon and radium are being investigated in 12 soils, seven of which are in Pennsylvania. Large changes in radon with time and some enrichment of radium in the A soil horizon are observed. ACD: March 1990.

A. A. SOCOLOW, Consulting Geologist. **Screening for Potential Waste-Disposal Sites** [eastern Pa.]. Identification of sites potentially usable for various types of waste-disposal facilities. Screening is based on geologic, hydrologic, topographic, seismologic, and soils criteria. ACD: Ongoing.

KEITH WILLIAMS, Kutztown Univ. **Radon Concentrations and Micro-Climatic Factors in Shofers Cave, Berks County.** ACD: Dec. 1989.



GENERAL GEOLOGY

J. H. BARNES and S. W. BERKHEISER, JR., Pa. Geol. Survey. **Common Rocks and Minerals of Pennsylvania.** A complete revision of Pennsylvania Geological Survey Educational Series 1, a booklet that introduces the reader to basic concepts regarding the mineralogy and petrology of the state. ACD: 1989.

J. A. HARPER, Pa. Geol. Survey. **Geology of the Pittsburgh Area** [Allegheny Co. and environs]. A revision of Pennsylvania Geological Survey General Geology Report 59. ACD: 1989.

A. L. HOERSCH, LaSalle Univ., and C. G. WISWALL, West Chester Univ. **Guidebook to the Geology of the Philadelphia Area.** A revision of General Geology Report 41, originally published by the Pennsylvania Geological Survey in 1964 and written by B. K. Goodwin. ACD: Spring 1990.

D. M. HOSKINS, Pa. Geol. Survey. **The Forgotten Geology of William Darby.** A chapter is being prepared for a GSA special paper on the geological contributions of William Darby to Pennsylvania and the southwestern United States. ACD: Sept. 1989.

J. M. HUSCH, Rider Coll., P. E. OLSEN, Columbia Univ., and M. J. HOZIK, Stockton State Coll. **Geology of the Newark Basin: A GSA Memoir in Honor of Franklyn B. Van Houten.** Approximately 30 manuscripts covering all aspects of the geology of the basin will be included along with an updated map (1:250,000) and stratigraphic column. ACD: June 1991.

E. F. KOPPE, Consulting Geologist. **Coal Geology and Resources Between the Northern Anthracite Field and the Western Bituminous Coal Region of Pennsylvania** [Lycoming, Tioga, Bradford, and Sullivan Cos.]. ACD: Ongoing.

G. H. MYER, Temple Univ. **General Geology of Valley Forge State Park.** Results will include geologic map, schematic cross sections of geology, topographic sections of streams, various photographs, and credits to students (1982-86 summer camp). ACD: Dec. 1989.

GEOCHEMISTRY

FRED BALDASSARE, Pa. Dept. of Environ. Resources, Bur. of Oil and Gas Mgmt., and C. D. LAUGHREY, Pa. Geol. Survey. **^{13}C and Hydrogen (Deuterium) Signatures of Methane from Various Sources in Southwestern Pennsylvania.** The purpose is to determine if methane from different sources exhibits unique stable isotope signatures. Samples will be analyzed for ^{13}C and hydrogen (deuterium) isotope composition. Study is in the early stages. Sampling is to begin in early summer 1989. ACD: Spring 1990.

W. A. CRAWFORD, Bryn Mawr Coll., and J. W. VALLEY, Univ. of Wisconsin. **Origin of Graphite in the Pickering Gneiss and the Franklin Marble, Honey Brook Upland, Pennsylvania Piedmont.** δ^{13}C values in graphites from fine-grained Pickering gneiss indicate an organic source for the carbon. δ^{13}C values from Franklin marble indicate a sedimentary carbonate protolith. δ^{13}C values from anatectic pegmatites in Pickering gneiss indicate an exchange of carbon isotopes during anatexis between gneiss and marble. Calcite-graphite thermometry gives temperatures of 680°C for upper amphibolite facies and 748°C for granulite facies metamorphism. ACD: 1989.

R. K. KOTRA, Project Chief, U.S. Geol. Survey. **Organic Geochemistry.** A set of black shale samples from Bucks County (Lockatong Formation, Newark basin) supplied by the Pennsylvania Geological Survey was analyzed for source rock potential. Pyrolysis data indicated that the samples are beyond a stage of metamorphism where any meaningful organic geochemical data could be obtained. This completes project work involving material from Pennsylvania.

P. C. LYONS, Project Chief, U.S. Geological Survey. **Late Paleozoic Depositional and Coalification Processes.** Regional coalification and diagenesis in the Pennsylvanian of the northern Appalachian basin are being studied using vitrinite reflectance, H:C and O:C atomic data, illite crystallinity, conodont coloration, and argon geochemistry of feldspar from carboniferous sandstone. Coalification and diagenesis will be related to structure, deposition, and tectonics.

J. M. McNEAL, Project Chief, U.S. Geol. Survey. **Geochemical Exploration Techniques for the Eastern Triassic Basins.** No new work will be initiated in Pennsylvania. The NURE data for the geochemical maps of the Newark and Gettysburg basins have been compiled. All that remains is to prepare a formal publication. ACD: 1990.

M. L. MORGART, Pa. Dept. of Environ. Resources, Bur. of Oil and Gas Mgmt. **The Effects of Water Flooding for Enhanced Oil Recovery on Groundwater Aquifers in Washington County.** Organic and inorganic samples are being collected from 23 water wells over a 12-month period. Analyses will be interpreted to determine geochemical effects of water flooding on local aquifers. Sampling is nearing completion. ACD: 1990.

M. K. RODEN and D. S. MILLER, Rensselaer Polytechnic Inst. **Apatite Fission-Track Thermochronology of the Pennsylvania Appalachian Basin.**

C. B. SCLAR and P. H. BENOIT, Lehigh Univ. **A Comparative Chemical Study of the "Vein" Chromite and the Massive Chromite from the Wood's Chrome Mine, Southeastern Pennsylvania.** Electron-microprobe analyses of the "vein" and massive chromite from the Wood's mine show that the "vein" chromite has a unique chemical signature. The genetic significance of this signature is now being evaluated. ACD: June 1990.

F. E. SENFTLE, Project Chief, U.S. Geol. Survey. **Neutron Activation.** Our previous research with hydrothermal pyrite heated to less than 410°K in an oxygen-stained atmosphere shows that the surface oxidation takes place forming small superparamagnetic particles of magnetite on the pyrite surface. Similar experiments with pyrite in a coal from Washington County show that a similar mechanism takes place when pyritic coal is heated, even though reducing coal decomposition gases are formed in the vicinity of the pyrite grains.

E. C. SPIKER, Project Chief, U.S. Geol. Survey. **Environmental Isotopic Geochemistry.** A study of organic matter in shales of the eastern Mesozoic basins, including a few samples from Pennsylvania.

GEOMORPHOLOGY

T. W. GARDNER, K. F. CONNORS, and R. L. DAY, Pa. State Univ. **Variation of Geomorphometrics with Digital Elevation Data Resolution Across the Physiographic Provinces of Pennsylvania.** An investigation of the effects of digital elevation data resolution on geomorphometrics across different physiographic provinces in Pennsylvania. Authors will quantify how measures of landscape features vary as scale varies from 1:24,000 to global. ACD: 1991.

T. W. GARDNER, J. B. RITTER, T. W. BELL, K. F. CONNORS, N. M. PINTER, and C. A. SHUMAN, Pa. State Univ. **Grèzes Litées in the Valley and Ridge Province of Central Pennsylvania, USA: Regional Distribution, Morphology, and Depositional Processes.** Characterization of grèzes litées on highly fractured, fissile Ordovician, Silurian, and Devonian shales includes stratigraphy, sedimentology, geomorphic attributes, and a depositional model. ACD: Winter 1989.

J. V. HAMEL and E. A. HAMEL, Hamel Geotechnical Consultants. **Depositional Chronology of Surficial Soils, G.R.O.W.S. Landfill Vicinity, Bucks County, Pennsylvania** [along Delaware River in Falls Twp.]. G.R.O.W.S. landfill is situated on a terrace complex consisting of braided outwash that was deposited and then eroded by the Delaware River in late Wisconsinan glacial time. Subsequent fluvial deposition on the terrace complex has been insignificant. ACD: Dec. 1989.

J. B. RITTER and T. W. GARDNER, Pa. State Univ. **Temporal Variation in Water and Sediment Discharge During Drainage Network Evolution in Disturbed Surface Mine Watersheds** [Centre and Clearfield Cos.]. ACD: Jan. 1990.

W. D. SEVON, Pa. Geol. Survey. **Pennsylvania's Polygenetic Landscape—Revisited** [Dauphin and Cumberland Cos.]. Guidebook to accompany field trip at 20th Annual Geomorphology Symposium, Carlisle, Pa., October 20–22, 1989. ACD: Oct. 1989.

RUDY SLINGERLAND and KEVIN FURLONG, Pa. State Univ. **Geodynamic and Geomorphic Modelling of the Late Paleozoic Ancestral Appalachians** [Middle Atlantic States]. We are using critical-wedge theory in conjunction with a flexural-loading model to estimate the mean elevation and width of the Carboniferous and Permian Alleghanian Highlands. ACD: Fall 1990.

G. H. THOMPSON, JR., Elizabethtown Coll. **Geomorphology of the Lower Susquehanna River Valley.** ACD: Ongoing.

W. B. WHITE, Pa. State Univ. **Caves of Pennsylvania.** The objective is to prepare a complete catalog of the caves of Pennsylvania including maps and descriptions of the caves. Work on the counties of the Ridge and Valley province is about 80 percent complete. ACD: 1990.

W. B. WHITE and E. L. WHITE, Pa. State Univ. **Studies of the Appalachian Karst.** A comprehensive investigation of karst landforms and karst drainage basins includes studies of basin morphology and evolution, processes of sinkhole development, and the role of caves in paleohydrology in the entire Appalachian Highlands. ACD: Ongoing.

GEOPHYSICS

E. R. KING, Project Chief, U.S. Geological Survey. **Development of Geophysical Techniques for Investigating Occurrence of Polymetallic Sulphides in the Eastern United States.** The project includes the Blue Ridge and Piedmont provinces of Pennsylvania.

K. P. KODAMA and JOHN STAMATAKOS, Lehigh Univ., and ART GOLDSTEIN, Colgate Univ. **The Effects of Simple Shear Strain on Remanence.** A detailed rock magnetic/paleomagnetic study of Silurian units in central Pennsylvania. We are trying to determine if remanence rotates as a passive line or as if carried by rigid particles during noncoaxial strains. ACD: June 1990.

J. D. UNGER, Project Chief, U.S. Geol. Survey. **Seismic-Reflection Investigations of Mesozoic Basins, Eastern United States.** Research to date has resulted in promising possibilities for displaying interpreted seismic-reflection data along with gravity, magnetic, and refraction information as three-dimensional models of the crust in and around the Mesozoic basins.

GLACIAL GEOLOGY

D. D. BRAUN, Bloomsburg Univ. **Correlation of Late Wisconsinan Recessional Ice Margins Across North-Central and Northeastern Pennsylvania.** Ice-margin positions can be determined from the sequence of proglacial lakes and sluiceways in north-central Pennsylvania and from outwash morphosequences in northeastern Pennsylvania. ACD: Potter-Tioga Cos., 1989; Bradford-Sullivan Cos., 1990; Pocono region, 1992-95.

D. D. BRAUN, Bloomsburg Univ. **Pre-Wisconsinan Glacial Geology of Eastern Pennsylvania.** Mapping of the distribution and extent of pre-Wisconsinan glacial margins is being extended to the southeast and northwest of the Anthracite region. ACD: 1991-92.

HYDROLOGY

T. F. BUCKWALTER, U.S. Geol. Survey, and M. E. MOORE, Pa. Geol. Survey. **Groundwater Resources of Warren County.** Countywide groundwater conditions will be evaluated. Extensive water-quality data will be used to determine impacts of oil and gas production on the resource. A revised geologic map will be included. ACD: Dec. 1989.

D. M. DIODATO, Argonne Nat. Lab., and R. R. PARIZEK, Pa. State Univ. **Quantitative Characterization of Unsaturated Fluid Flow Behavior in Disturbed Mine Spoil: Two Nuclear Methodologies** [Clarion, Pa.]. The project involved two subexperiments associated with a field-scale acid mine drainage abatement demonstration project. One subexperiment characterized moisture content, bulk density, total porosity, and unsaturated hydraulic conductivity using nuclear-probe methodologies. The other determined unsaturated hydraulic conductivity using a tracer study and post-sampling neutron-activation analysis. ACD: Completed.

M. D. GUEBERT and T. W. GARDNER, Pa. State Univ. **Measurement of Shallow Subsurface Water Movement on a Disturbed Land Watershed** [Centre Co.]. Purpose is to determine the volume and timing of throughflow in reclaimed surface-mined land, and the relationships of water movement to various measured properties, such as hydraulic conductivity, soil moisture, bulk density, and soil texture. ACD: Fall 1990.

PATRICIA LIETMAN, EDWARD KOERKLE, KEVIN KOSTELNIK, DOUGLAS CHICHESTER, DAVID FISHEL, MICHAEL LANGLAND, DAVID HALL, and LINDA GUSTAFSON-MINNICH, U.S. Geol. Survey, and M. J. BROWN, Pa. Dept. of Environ. Resources. **Conestoga Headwaters Rural Clean Water Project** [Upper Conestoga River basin, Lancaster Co.]. Water-quality changes resulting from the implementation of agricultural best management practices were evaluated for nonpoint-source contaminants. Agricultural areas underlain by carbonate rock were found to be most susceptible to contamination. Pesticides were most prevalent and nitrate concentrations typically exceeded drinking water standards for these areas. ACD: Sept. 1992.

RICHARD LOWRIGHT and PATRICIA SCHNEIDER, Susquehanna Univ. **A Survey of Water Quality in the Tonoloway and Keyser Formations in Snyder County.** Water samples collected from 35 wells receiving water from only these aquifers were analyzed for naturally occurring chemicals. Preliminary interpretations are that both local and intermediate flow systems were encountered and that this is the primary cause of variation in water quality. ACD: Aug. 31, 1989.

C. R. MOORE, U.S. Geol. Survey. **Effects of Land Use and Organochlorine Insecticide Concentrations on Benthic-Invertebrate Diversity Indices of Selected Streams in Chester County.** The objectives are to relate land use practices and changes to the occurrence and concentrations of organochlorine insecticides in stream-bottom sediments and to diversity-index trends of stream benthic invertebrates. A sediment core was taken from the former Icedale Lake for radionuclide dating and determination of organochlorine insecticide inputs into the lake. ACD: Sept. 30, 1990.

DENNIS RISSER, U.S. Geol. Survey. **Evaluation of Methods to Delineate the Area of Groundwater Contribution to Wells in Various Hydrogeologic Settings in Pennsylvania.** ACD: 1993.

J. B. RITTER and T. W. GARDNER, Pa. State Univ. **Runoff Curve Numbers for Disturbed Surface Mine Watersheds, Central Pennsylvania** [Centre and Clearfield Cos.]. ACD: Sept. 1989.

CHRIS SARSONY and RICHARD LOWRIGHT, Susquehanna Univ. **Comparison of Methods of Peak Streamflow Estimation for Penns Creek, Central Pennsylvania.** The tabular, graphical, and multiple-regression peak streamflow estimation methods were applied to a portion of Penns Creek, central Pennsylvania. The multiple-regression method was the easiest to perform and the most accurate of the methods when compared to actual gaging values. ACD: May 12, 1989.

L. A. SENIOR and K. L. VOGEL, U.S. Geol. Survey. **Radium and Radon Occurrence in Groundwater of the Chickies Formation, Southeastern Pennsylvania.** ACD: Sept. 30, 1989.

R. A. SLOTO, U.S. Geol. Survey. **Groundwater Resources of Chester County.** The objective is to produce a comprehensive report describing the groundwater resources of Chester County. ACD: Sept. 1990.

M. J. VALENTINE, W. Va. Univ. **Investigation of Lineaments and Groundwater Chemistry as Exploration Tools of Natural Gas and Groundwater in Indiana County.** Lineament mapping (on 7.5-minute quadrangles) has been completed. In progress is statistical-trend delineation between lineaments and water and gas yields and between water well geochemistry and gas production. ACD: Sept. 1989.

K. L. VOGEL, U.S. Geol. Survey. **Geohydrology and Simulation of Groundwater Flow in the Red Clay Creek Basin, Chester County, Pennsylvania, and New Castle County, Delaware.** A digital groundwater-flow model will be used to predict the effects of increasing groundwater development on base flow and groundwater levels. A data-collection network (9 rain gages, 16 observation wells, and 3 stream gages) is in place. A water-table map is being constructed. ACD: Sept. 30, 1991.

K. E. WHITE, U.S. Geol. Survey. **Base Flow of Selected Pennsylvania Streams.** Base-flow separations are done for all continuous-record stations in Pennsylvania that have at least 10 years of record. This report will include three methods of hydrograph separation: local minimum, fixed interval, and sliding interval. ACD: June 30, 1989.

D. R. WILLIAMS, U.S. Geol. Survey, and T. A. McELROY, Pa. Geol. Survey. **Geology and Water Resources of Indiana County.** Field work has been completed. Two-, 4-, 24-, and 72-hour pump tests were conducted at the Plumville well nest. All field data have been entered into computer data bases. Compilation of the geologic map is 30 percent complete. ACD: 1990.

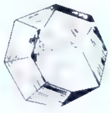
DAWNA YANNACCI, Pa. Geol. Survey, and DANIEL HIPPE and DENNIS LOW, U.S. Geol. Survey. **Aquifer Characteristics of the Rocks of Pennsylvania.** A comprehensive summary of the hydrogeologic characteristics of individual formations and regional flow systems will be developed using available data. The study will be published in three parts, the first covering southeastern Pennsylvania. ACD: Sept. 1989.

IGNEOUS AND METAMORPHIC PETROLOGY

P. C. CARNES and G. H. MYER, Temple Univ. **Petrology of the Castle Rock Ultramafic Enclave** [Newtown Square, Delaware Co.]. ACD: Jan. 1990.

J. M. HUSCH, Rider Coll. **Geochemistry and Petrogenesis of Early Jurassic Diabases, Central Newark Basin** [eastern Pa. and west-central N. J.]. The lateral and upward migration of residual liquids after pyroxene-dominated fractionation appears to be a common process in the diabases. The classic view of these sheets being differentiated by vertically directed, olivine-dominated fractionation is not supported. ACD: June 1991.

D. W. VALENTINO and R. T. FAILL, Pa. Geol. Survey. **Metamorphic Isograd Map of the Southeastern Pennsylvania Piedmont.** A preliminary isograd map has been compiled using new and published data. Complex isograd patterns suggest that the regional metamorphic gradients have been modified by post-metamorphic tectonism. ACD: March 1991.



MINERALOGY

C. G. WISWALL, West Chester Univ., and LISA SENIOR, U.S. Geol. Survey. **Solid Phase Source of U and Th in the Chickies Quartzite** [southeastern Pa.]. ACD: Sept. 1989.

PALEONTOLOGY

N. C. ARENS, Harvard Univ., and R. J. CUFFEY, Pa. State Univ. **Bryozoan Fauna, *Prasopora* Taphonomy, and Tempestite Storm Deposits in the Coburn and Salona Limestones (Ordovician) of Central Pennsylvania.** ACD: May 1989.

R. M. FELDMANN, J. T. HANNIBAL, D. J. MULLETT, B. A. SCHWIMMER, D. TSHUDY, A. B. TUCKER, and R. W. WEIDER, Kent State Univ. **The Paleoecology of *Echinocaris randallii* Beecher from the Vicinity of Drake's Well, Titusville, Pennsylvania.** *Echinocaris randallii* Beecher is reported from the Corry Sandstone for the first time. Evidence based upon brachiopods suggests a Late Devonian, rather than Mississippian, age for the Corry at this locality. ACD: April 1989.

A. G. HARRIS, U.S. Geol. Survey, and CARMEN MOY, Pa. State Univ. [No title provided.] The purpose is to date and paleoecologically characterize the upper part of the Bellefonte Dolomite in the vicinity of State College. For the first time, identifiable palynomorphs have been recovered from the Bellefonte Dolomite; these represent a very shallow water carbonate palynofacies. Conodonts from the same horizons as the palynomorphs precisely place the palynomorph assemblages within middle Whiterockian conodont zones of the North American Midcontinent Province zonation.

ALBERT KOLLAR, Carnegie Mus. of Natural History and Univ. of Pittsburgh. **The Redescription and Reillustration of the Brachiopods from the Cuyahoga and Logan Formations (Lower Mississippian), Upper Waver-**

ly Group of Central and Southern Ohio [includes Cuyahoga Fm. of western Pa.]. ACD: Oct.-Nov. 1989.

R. LITWIN, Project Chief, U.S. Geol. Survey. **Mesozoic Palynology of the Atlantic Continental Margin.** Field work is ongoing in the Gettysburg basin in an attempt to improve the current palynological age determinations in the New Oxford Formation and Gettysburg Shale. A study is also underway to examine the possibility that the Jacksonwald syncline contains a nearly continuous sedimentary sequence through the Triassic-Jurassic boundary interval; the fossil assemblages examined so far do not conclusively confirm the boundary, and additional samples are being sought from both lower and higher in the section.

W. A. OLIVER, JR., U.S. Geol. Survey. **Corals and Biostratigraphy of the Keyser and Helderberg Limestones in the Appalachian Basin** [N. Y., N. J., Pa., Md., W. Va., and Va.]. Rugose corals are being described and their stratigraphic and areal distribution analyzed from the fine-grained, stromatoporoidal facies of Pridolian and Lochkovian age. ACD: Ongoing.

W. A. OLIVER, JR., U.S. Geol. Survey. **The Principal Pridolian and Lochkovian Coral Assemblages or Communities in Eastern North America.** Review of subject for ecostratigraphy final report. ACD: Completed.

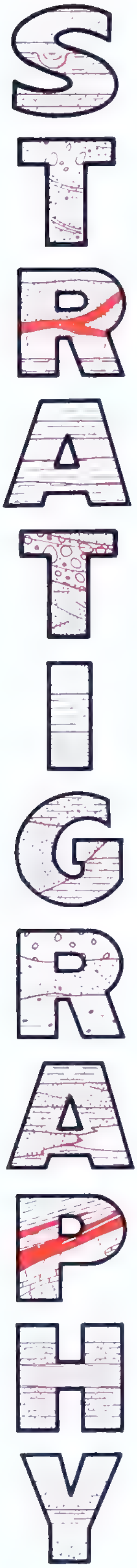
C. WNUK, Project Chief, U.S. Geol. Survey. **Paleoecology of Coal and Coal-Bearing Rocks.** The objective is to develop an improved understanding of the environmental, edaphic, ecological, and climatological factors that influence the development of peat-forming plant communities and, consequently, affect coal quality, thickness, and distribution. Investigations are concentrating on *in situ* floras that are found in underclays beneath coal beds. Intensive study of a fossil assemblage that occurs in the underclay of the Mammoth #8 coal bed in the Shamokin quadrangle has led to the reconstruction of the growth form and ontogeny of the lycopod *Bothrodendron punctatum*.

SEDIMENTOLOGY

EDWARD COTTER and JOHN LINK, Bucknell Univ. **Clinton Group Sedimentary Ironstones, Central Pennsylvania.** Field examination is nearly complete; petrography has begun; chemical analyses are expected this summer. All aspects of description and interpretation are more complex than expected, and origin is related to conditions at the site of initial accumulation, to several mechanisms and locations of resedimentation, and to several phases of diagenesis. ACD: Summer 1990.

RUDY SLINGERLAND and DAVID SWETLAND, Pa. State Univ. **Circulation and Sediment Transport Modelling in the Late Devonian Catskill Epeiric Sea** [central and western Pa.]. Since last year we have completed 40 numerical experiments using a three-dimensional hydrodynamic model of circulation in the Late Devonian Catskill Sea, five of which include density stratification. The results, consistent with outcrop studies, indicate that the producing sandstones of the Council Run gas field are shore-parallel shelf sand ridges. ACD: 1990.

TAMMY SUTER, W. Va. Univ. **Origin and Significance of Mississippian Polymictic Diamictites in the Central Appalachian Basin** [western Md. and northeastern Pa.]. ACD: May 1990.



A. D. GLOVER, C. H. DODGE, L. J. LENTZ, J. R. SHAULIS, and V. W. SKEMA, Pa. Geol. Survey. **TASIC (Temporarily Available Stratigraphic Information Collection).** A continuing program to collect stratigraphic data and coal samples for analysis from active coal and clay mines and from drill cores in north-central and western Pennsylvania. The project will provide data for future mapping and regional resource evaluation. ACD: Ongoing.

W. M. GOODMAN and CARLTON BRETT, Univ. of Rochester. **Stratigraphic Dynamics of the Medial Silurian (Wenlockian) Northern Appalachian Foreland Basin** [Pa., N. Y., Ontario, Md., W. Va., and Ohio]. Laterally traceable hematitic conglomerate/phosphatic pebble/complex shell beds in upper Clinton strata define several unconformity-bound depositional units. A Vail-type depositional sequence approach is being applied to reconstruct mid-Silurian sea-level and tectonic histories. ACD: May 1990.

J. D. INNERS, Pa. Geol. Survey, W. E. EDMUNDS, Consulting Geologist, and L. J. LENTZ, Pa. Geol. Survey. **Pottsville Stratigraphy and the Mid-Carboniferous Boundary in the North Half of the Anthracite Region** [northeastern Schuylkill Co., northwestern Carbon Co., and Luzerne Co.]. Objective is to determine the nature and areal extent of the basal Pottsville disconformity that is evident in the Northern Anthracite field and the northern part of the Eastern Middle field. ACD: March 1990.

B. N. SHAFFER, W. Va. Univ. **Stratigraphy and Sedimentation of the Acadian Clastic Wedge in Southwestern Pennsylvania.** This study, to start in the summer of 1989, will involve subsurface correlation to determine geometry, trends, depositional environments, and genetic origin of oil- and gas-producing sandstones of Upper Devonian/Lower Mississippian age.

R. C. SMITH, II, and S. W. BERKHEISER, JR., Pa. Geol. Survey, and J. H. WAY, Lock Haven Univ. **Lower Devonian and Other Bentonites and Ash Beds** [Va. to Quebec]. Bald Hill Bentonite Beds A, B, and C have now been correlated from Monterey, Virginia, to Cherry Valley, New York. These as well as the Upper Ordovician bentonites and Tioga ash beds are associated with the drowning of carbonate platforms by major marine transgressions. ACD: Ongoing.

STRUCTURAL GEOLOGY

BARBARA BLOOMFIELD, Temple Univ. **Evidence of Martic Shear Zone Deformation in Rocks of the Honey Brook Upland, Northern Chester County.** ACD: Aug. 1989.

WAYNE BREWER and KEVIN SMART, Allegheny Coll. **Finite Strain Analysis and Deformation Mechanisms in Sandstones of the Homoclinal Portion of the Appalachian Plateau of Pennsylvania.** ACD: 1990.

R. T. FAILL, Pa. Geol. Survey. **Tectonic Map of Pennsylvania.** Map will show locations and names of anticlines, synclines, anticlinoria, structural fronts, thrust, normal, transcurrent, and other faults; basement contours; contours on top of the Onondaga Formation; earthquake epicenters; radiometric dates; nappes and terranes; metamorphic isograds; and other sundry tectonic features. ACD: Dec. 1989.

M. B. GRAY, Univ. of Rochester. **Structural Evolution of the Southern Anthracite Region.** Data on the orientation and relative timing of mesoscopic and microscopic structures will be integrated with the large-scale fault and fold geometry to produce a model for the evolution of the Southern Anthracite region. ACD: 1991.

M. L. HILL, Temple Univ., and D. W. VALENTINO, Pa. Geol. Survey. **Structure of the Martic Zone (Peach Bottom-Trenton Zone), Southeastern Pennsylvania Piedmont.** ACD: 1992.

E. M. HOPKINS, Univ. of Pittsburgh at Bradford. **Effects of Sea-Level Fluctuation and Syndepositional Tectonism on Late Devonian Shoreline Architecture and Depositional Environments in North-Central Pennsylvania and Western New York.** Stratigraphy within the "Bradford" and "Venango" wedges suggests architectural control by features associated with reactivated basement fault zones parallel to and perpendicular to the curving Appalachian basin axis. Sandy sediment dispersal systems repeatedly occupied these features as the Late Devonian sea spasmodically transgressed and regressed across the Catskill coastal plain. ACD: Aug. 1989.

ASSAD IRANPANAH, Univ. of Pittsburgh at Bradford. **Brittle Fracture Analysis of the Middle-Upper Ordovician Carbonates in the Union Fur-**

nace Section, Southeast Limb of the Nittany Anticlinorium. A master joint set having a mean value of N23°W (parallel to σ_1), and a minor joint set having a mean value of N78°E (parallel to ε_x) were identified in the field. The early formed master joint set is believed to be both a major conduit and a sink into which chemically charged fluids migrated and reprecipitated dissolved calcite. The conjugate en-echelon vein arrays and the pressure-solution surfaces suggest a stretching and shortening of $\Delta\bar{v}$ with $2\theta = 110°$. ACD: Dec. 1989.

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R. P. NICKELSEN, Bucknell Univ., JEFF WALKER, Vassar Coll., and KAREN MULLANEY, Smith Coll. **Phyllosilicate Reorientation and Recrystallization During Formation of a Marcellus Formation Cleavage Duplex.** ACD: Fall 1989.

L. B. PLATT, Bryn Mawr Coll., and ANDREW QUARLES and STACEY TYBURSKI, Univ. of Texas at Austin. **Strain Recorded by Fossils in the Valley and Ridge Province.** Following the work of Nickelsen and Faill, we are quantifying strain in fossils and cleavage to determine strain sequence and amounts of pure and simple shear. ACD: May 1989.

C. A. SHUMAN, Penn State Univ. **Remote Sensing and Field Analysis of the Muddy Creek Lineament, York County.** ACD: Early 1990.

C. A. SHUMAN, Penn State Univ. **Use of Multiple-Scale Remote-Sensing Imagery and Ground-Based Studies to Assess Fracture Indicators Across the Appalachian Orogen** [nine study blocks (six quads. each) distributed from Piedmont to Plateau]. In order to more completely characterize fracture indicators (lineament and fracture-trace features) observed on aerial photographs and remote-sensing imagery, multiple scales of imagery (from 1:500,000 to 1:20,000) will be used and typical fracture mapping will be employed to define the relationship between fracture patterns and their geomorphic expression. Scale relationships (fractal?) and the role of *in situ* stress on these features will also be investigated. ACD: 1990.

D. W. WATSON, Slippery Rock Univ. **Structural Study of Slippery Rock Creek Gorge Area, McConnells Mill State Park.** ACD: Ongoing.

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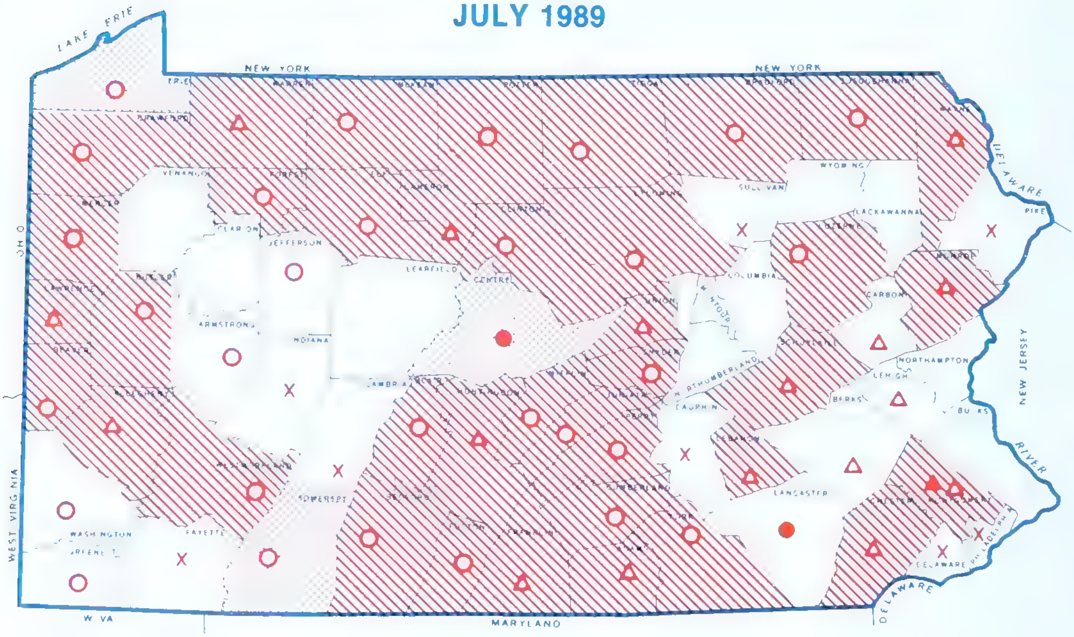

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ON THE COVER: "The Crater" at Petersburg National Battlefield, Petersburg, Virginia. This hummocky depression marks the site of the explosion of the "Petersburg mine," prelude to the Civil War "Battle of The Crater." The white monument on the far side of the depression honors Major-General William Mahone, C.S.A., who led a vigorous counterattack of Virginia and Georgia brigades that stopped the Union advance on the morning of July 30, 1864. Photograph by J. D. Inners.

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Groundwater-Quality Protection—the Priority Issue

The National Conference of State Legislatures recently identified groundwater-quality protection as the national priority issue for 1989. It received 16 first-place votes of legislatures, nearly three times the number of votes as the next most important issues of financing water-supply and waste-treatment facilities, and land use management. Thus groundwater-quality protection appears to be where the action is!

How does a Geological Survey respond to such issue identification when investigation of groundwater is a major part of our program? Do we have a role to play in groundwater-quality protection, and, if so, what is this role?

The Pennsylvania Geological Survey has no legislated authority to protect a resource; our authorizing legislation only broadly charges us to survey the geology and chemistry of the waters of the Commonwealth in order to characterize this resource. We are investigators without an advocate's role. Groundwater in Pennsylvania has been studied for over a half-century by the U.S. Geological Survey through financial cooperation with our Bureau and, for the past 15 years, these studies have been augmented with studies by our own hydrogeologists. Most investigations have focused on groundwater as a resource, and availability has been the major emphasis. Collection of chemical data, although subordinate to availability, has been included for decades. All of these data are used by other Pennsylvania bureaus that have authority to manage the quantity and protect the quality of the resource. With the advent of environmental protection, there developed a division of labor in which the geological surveys produce nonadvocacy assessments of the resource and regulatory agencies make decisions on the use of the resource.

Assessment and use decisions do not lead to protection, however. To protect groundwater one should focus at the portion of the hydrogeologic cycle where it begins to be groundwater—the area of recharge. This requires defining the limits, topography, and hydrogeology of the watershed area that broadly defines the equivalent groundwater basin. Pennsylvania has over 60,000 major and minor watersheds. Their limits ignore political boundaries. Each is unique; thus, approaches such as limiting protection only to areas around wells are unlikely to suffice. More importantly, once defined, the importance of each groundwater basin must be determined. This activity begins the process of determining land use, historically a local government decision.

There is more here than any level of government can independently handle. State must cooperate with state where watersheds cross state lines. Local government must cooperate with state government to set value. State geological surveys and the U. S. Geological Survey should continue nonadvocacy assessments but should accept a mediator's role to resolve issues. We all must work towards solving the public problem of groundwater-quality protection.

Donald M Hoskins

Donald M. Hoskins
State Geologist

IN MEMORIAM
William Culp Darrah (1909-1989)

William C. Darrah, educator, geologist, botanist, and historian, loved life, and he chose to share with others his genuine enjoyment of discovery and learning through his writing and teaching. His *A Critical Review of the Upper Carboniferous Floras of the Eastern United States* (1970) and nearly a hundred professional papers made his name familiar to many paleontologists in Pennsylvania and throughout the United States. It is interesting to note that early in his career William (Bill) Darrah developed an interest in the ancient conifers, especially *Walchia*. At the time of his death, he had just completed a manuscript with Paul Lyons, *The Earliest Conifers in North America: Upland and/or Paleoclimatic Indicators?*, which has been accepted for publication in *PALAIOS*. Most recently, Bill had hoped to present a paper on the Dunkard at the July 1989 IGC in Washington, D. C., having previously attended the International Geological Conference in the United States in 1933.

Over his lifetime, Bill made great contributions to paleobotany and geology. Even so, many still may know little about his extraordinary life.

William Darrah was born in Reading, Pennsylvania, on January 12, 1909. He received his B.S. degree from the University of Pittsburgh in 1931. Following graduate studies, he went on to Harvard University in 1934, first as a research assistant and then as research curator in paleobotany at the Botanical Museum as well as faculty instructor in biology until 1942. During the war years, Bill worked as an assistant head research engineer in the Research and Development Laboratory of Raytheon Manufacturing Company of Waltham, Massachusetts, and remained there for nine years.

In 1951, he moved his family to Gettysburg, Pennsylvania, where he resumed his various research and writing activities. In 1953, he joined the faculty at Gettysburg College. Awarded a full professorship in 1963, he remained there until his retirement in 1976. Gettysburg College awarded him the honorary degree of Doctor of Humane Letters in 1977.

Throughout his long career, William Darrah published more than 13 books, including *Principles of Paleobotany* (2nd edition, 1960), *Textbook of Paleobotany* (1939), *The Exploration of the Colorado River* (2 volumes, 1940 and 1950), *Powell of the Colorado* (1951), and *Pithole: the Vanished City* (1972).

Although suffering from heart trouble and terminal cancer, Bill was always in good spirits. He was devoted to his family and remained committed to continuing his research and other educational pursuits. Interested in people, he was a patient listener, an enthusiastic talker, and a concerned guide to friends, colleagues, and students alike.

William Darrah was truly a remarkable man. All of us whose lives he touched so memorably will surely miss him.

By Elsie D. Morey, daughter of William C. Darrah

Colonel Henry Pleasants and the Military Geology of the Petersburg Mine—June–July, 1864

by Jon D. Inners
Pennsylvania Geological Survey

INTRODUCTION. July 30 of this year marked the 125th anniversary of the tragic "Battle of The Crater" at Petersburg, Virginia. Many readers have at least a passing knowledge of this Civil War incident, certainly one of the most bizarre in American military history. It is well described in Bruce Catton's Pulitzer Prize winning account of the last year of the war, *A Stillness at Appomattox*, and James McPherson devotes several pages to it in his recent one-volume history, *Battle Cry of Freedom*. You will remember that the tragic Union defeat at "The Crater" was preceded by the successful explosion of a "mine" dug out under the Confederate fortifications by anthracite miners from Schuylkill County, Pennsylvania. This article will focus on the geographic, geologic, and engineering aspects of the "Petersburg mine" and on the ingenuity of the man who designed it—Colonel Henry Pleasants of Pottsville.

PHYSIOGRAPHY AND GEOLOGY OF THE PETERSBURG AREA. Petersburg is located at the west edge of Prince George County in southeastern Virginia (Figure 1). Like Washington, D. C., Richmond, and many mid-Atlantic cities, it lies on the Fall Line—the limit of coastal navigation and the boundary along which the relatively unconsolidated Cretaceous and younger sediments of the Atlantic Coastal Plain overlap the indurated, mostly metamorphosed rocks of the Piedmont. The city actually lies about 12 miles east of the feather edge of the Coastal Plain sediments at a point where the Appomattox River has cut down to expose the Mississippian-age Petersburg Granite (Figure 2) (Calver and others, 1963; Frye, 1986).

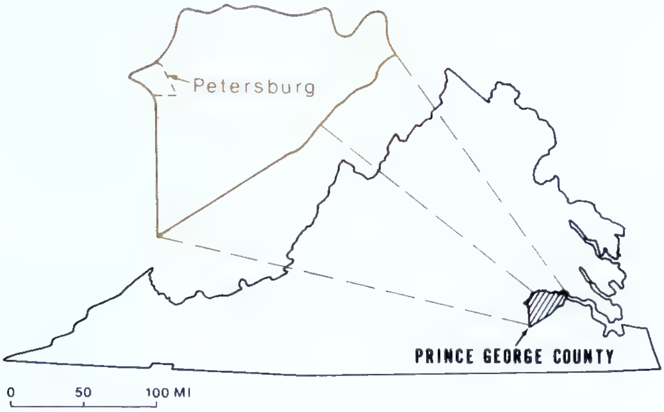

Figure 1. Location map.

Petersburg (population 18,000 in the early 1860's) is situated on the south bank of the Appomattox River, 10 miles upstream of the confluence of the Appomattox and the

James River estuary. To the south and east of the city a vague scarp bounds an "upland" area known geologically as the "Sunderland terrace," one of the many fluvial to marginal-marine terraces recognized on the Atlantic Coastal Plain (see Johnson and Berquist, 1989). East of Petersburg, Lieutenant Run and Poor Creek (0.75 mile farther to the east) have incised deep valleys into this terrace. The high, medial part of the interfluve between the two streams (maximum elevation, 144 feet) is the site of Blandford Cemetery, and, hence, has long been known as Cemetery Hill.

The Coastal Plain sediments at Petersburg are only about 150 feet thick and range in age from Cretaceous to Pleistocene (C. R. Berquist, written communication, 1989). Only the two Tertiary units shown in Figure 2—the Chesapeake Group and the Bacons Castle Formation—are pertinent to a discussion of the "Petersburg mine." The former consists of the Miocene-age Eastover Formation (dominantly marine clay and silt) and the Pliocene-age Yorktown Formation (mostly marine

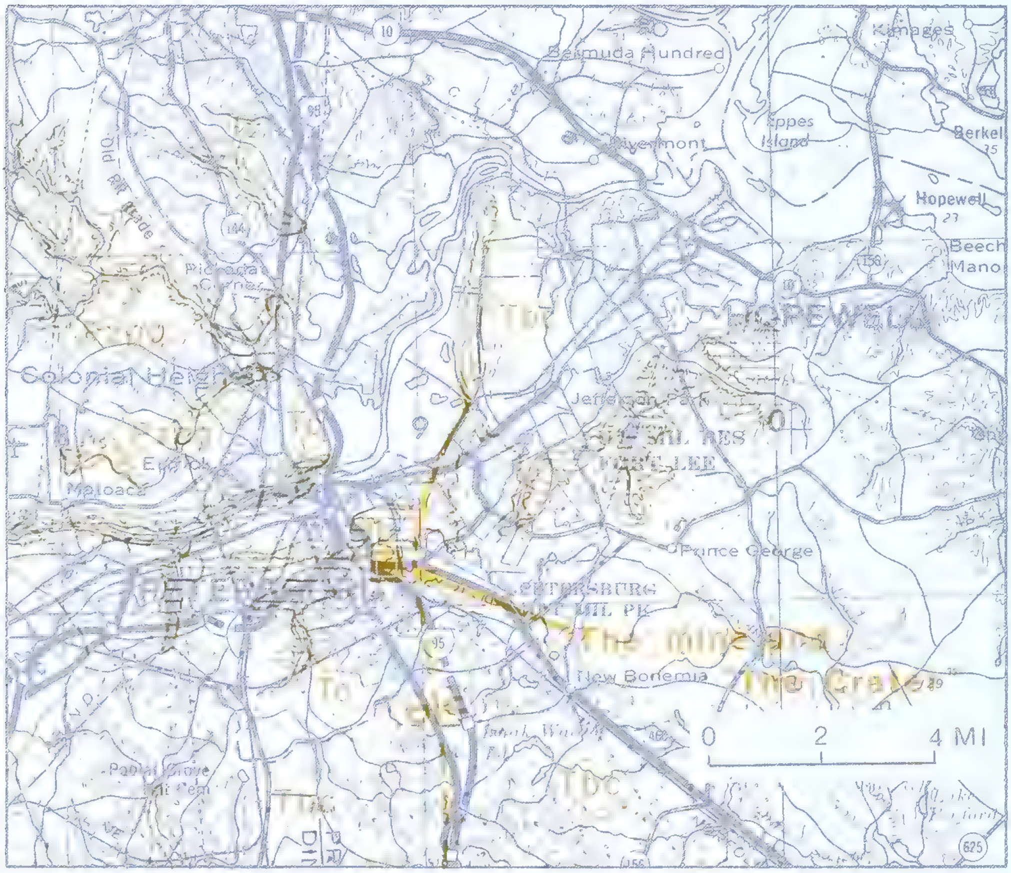

Figure 2. Greatly simplified geologic map of the Petersburg area (Tbc, Bacons Castle Formation; Tc, Chesapeake Group; Pzpg, Petersburg Granite). The fault shown is one of several in this part of the Coastal Plain (C. R. Berquist, written communication, 1989).

sand containing shell beds) (Ward and Blackwelder, 1980; Johnson and Berquist, 1989). The Bacons Castle Formation is a widespread blanket of Late Pliocene-age fluvial to intertidal sands that disconformably overlies the Chesapeake Group (Ramsey, 1987). The Bacons Castle caps the "Sunderland terrace" and forms the surficial material over most of Cemetery Hill, and the Chesapeake Group is exposed along the terrace scarp and in the valleys of Lieutenant Run and Poor Creek.

COLONEL PLEASANTS AND THE 48TH PENNSYLVANIA VOLUNTEER REGIMENT. Because of space limitations, it is not possible here to detail the movements of General Meade's Army of the Potomac (under Grant's ultimate command) and General Lee's Army of Northern Virginia that led to a virtual stalemate in front of Petersburg in mid-1864. The reader is referred to Catton (1953), McPherson (1988), and Davis (1986) for this background information. Suffice it to say that by the last week in June, both armies had succeeded in constructing extensive systems of trenches and redans (forts) out of the soft Coastal Plain sediments. Along most of the siege line east of Petersburg, the two armies were separated by a "no-man's-land" 500 to 1,000 feet or more wide. But at one point the rival picket lines approached to within 250 feet of each other. This was at Elliott's Salient just west of Poor Creek. Occupying the Union position opposite the rebel salient was the 48th Pennsylvania Volunteer Regiment.

Figure 3. Colonel Henry Pleasants (1833–1880), 48th Pennsylvania Veteran Volunteer Regiment, the originator and engineer of the Petersburg mine.

The 48th was part of General Ambrose Burnside's Ninth Corps and was composed of citizen-soldiers from Schuylkill County in the Anthracite region. It was commanded by Lieutenant-Colonel Henry Pleasants (Figure 3), a professional mining engineer from Pottsville. Pleasants, who had worked for the Philadelphia and Reading Coal and Iron Company just prior to the outbreak of the war, had earlier made a name for himself overseeing the excavation of the Sand Patch Tunnel on the Pittsburgh and Connellsville Railroad in western Pennsylvania (Bosbyshell, 1895). Among the more than 1,000 men composing Pleasants' regiment were 85 enlisted men and 14 commissioned officers who were coal miners.

THE PETERSBURG MINE. Dissatisfied with the virtual "sitzkrieg" that was developing at Petersburg and reportedly inspired by the overheard comments of one of his men (Pleasants and Straley, 1961), Colonel Pleasants conceived the idea of digging a mine from the regiment's position in Poor Creek to a point under the strong Confederate redan manned by Pegram's Battery at Elliott's Salient, filling a series of magazines at the end of the mine tunnel with black powder, and blowing a tremendous hole in the rebel line. Federal troops could then rush through the breach, capture Cemetery Hill, and drive the enemy from Petersburg. Since the Confederates were clearly running out of options, such an overwhelming victory might even bring the war to an abrupt end. Pleasants received wholehearted support for his plan from Burnside and lukewarm backing from Meade (who insisted that the mine could not be ventilated). On June 25, Pleasants and his men broke ground for the portal of the mine (Figure 4).

Before much work would be done, however, Pleasants had to find some way of computing the azimuth and distance of the Confederate fort from the Union position. Using an old theodolite acquired through Burnside (Meade's staff would not cooperate), he made five separate

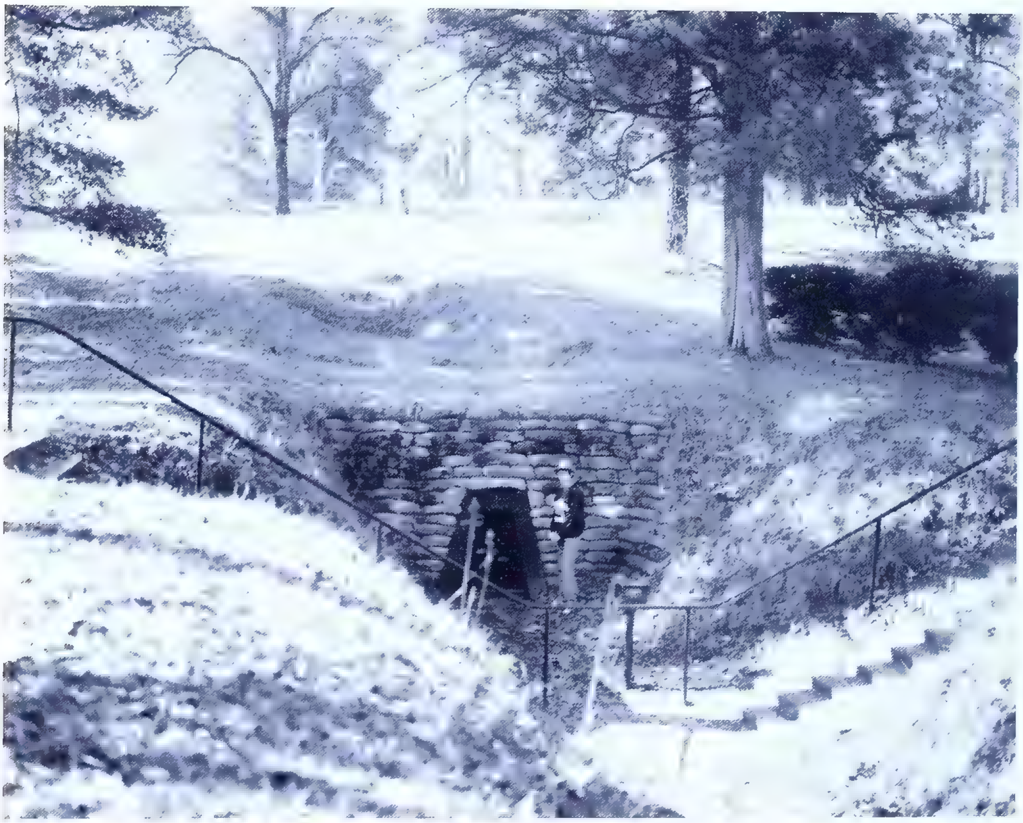

Figure 4. The restored entrance to the mine tunnel. Note the linear depression in the background that marks the course of the collapsed tunnel.

triangulations, exposing himself to rebel fire 10 times in the process. By averaging out the triangulations, he determined that the mine tunnel would have to be about 510 feet long in a direction of S70°W.

As shown in Figure 5, most of the mine was excavated in clays of the Eastover Formation (C. R. Berquist, written communication, 1989). (The gentle eastward dip of the sediments illustrated here was also indicated by Pleasants in the mine cross section that he prepared at the time.) The apparent bending of the strata at the portal is probably due to creep and colluviation along the edge of the Poor Creek valley. Note also the crook in the profile of the tunnel. This resulted from the fact that about 200 feet in from the portal, the miners encountered a bed of "marl," or heavy clay, which was extremely difficult to excavate. Pleasants ramped the tunnel slightly upward for several tens of feet to get the tunnel up into more easily dug material. The ramping, in combination with a slight eastward inclination necessary for drainage, brought the roofs of the completed gunpowder magazines to within 20 feet vertically of Pegram's redan.

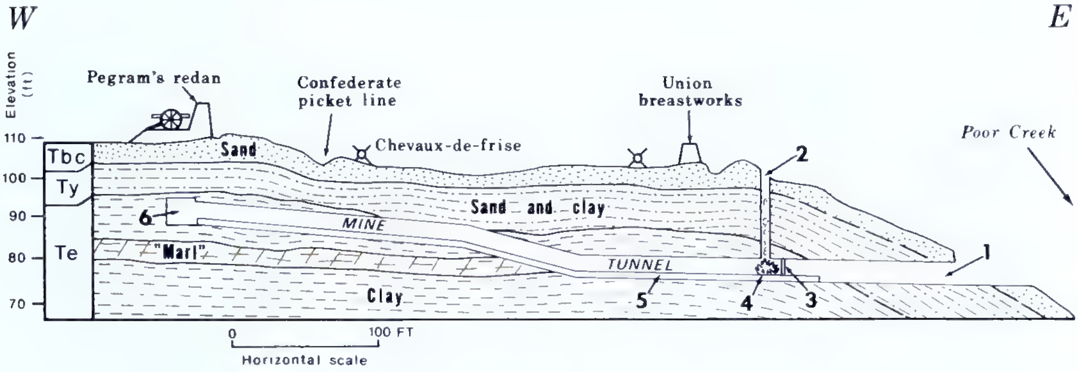

Figure 5. Geologic cross section of the mine, showing the relative positions of the Union and Confederate lines (Tbc, Bacons Castle Formation; Ty, Yorktown Formation; Te, Eastover Formation; 1, mine portal; 2, chimney; 3, partition; 4, "furnace"; 5, air duct; 6, magazines). Identification of the geologic materials is from Colonel Pleasants' detailed, but unscaled, drawings. The formational boundaries are from C. R. Berquist (written communication, 1989).

To solve the ventilation problem, Pleasants drew on his experience in ventilating railroad tunnels and underground anthracite mines (Bosbyshell, 1895). He cut out an area for a "furnace" to the side of the mine tunnel and then excavated a chimney upward to the surface. After putting a canvas partition across the tunnel just outside the furnace area, he ran a wooden duct through the partition and back to the working face. The hot air rising from the "furnace" created a draft that drew stale air away from the working face and fresh air in through the duct from outside the mine!

The ventilation problem was only one of the many obstacles to be overcome. Lacking cooperation from Meade and his headquarters staff, Pleasants and his men had to improvise constantly—straightening out their military issue picks to make more efficient digging tools, rigging up cracker-box slings to carry dirt out of the mine, braving Confederate detection in obtaining wood for bracing the roof and walls of the tunnel, and so forth. The only serious accident occurred on July 2, when a cave-in nearly trapped several men (Pleasants, 1938). But on July 23, less than one month after the "ground breaking," the excavation of the mine tunnel and the two lateral galleries for the magazines was completed.

Contemporary reports are unanimous in praising the Pennsylvanians' handiwork; no military mine in history was remotely comparable. The main tunnel was 510 feet long, 4.5 feet high, 4.5 feet wide at the base, and 2 feet wide at the top. The two lateral galleries were each about 38 feet long. The total length of the mine excavations was 585.8 feet. The volume of material removed amounted to more than 18,000 cubic feet, all of which was conveniently disposed of in a nearby cut on the Norfolk and Petersburg Railroad.

Pleasants and his men filled the eight magazines with 1,000 pounds of black powder each, tamped the entrances to the galleries and the end of the mine tunnel with sandbags and timbers to contain the blast, and set the fuse (which had to be spliced because of the short segments provided by Meade's engineers). By the evening of July 28, all was in readiness for the big blow. A day later, Meade called for the "springing of the mine" at 3:30 a.m. on July 30, and Burnside began moving his 9th Corps troops into position for the assault.

THE CRATER AND ITS AFTERMATH At 4:44 a.m., July 30, the mine was "sprung." (The fuse went out at a splice and had to be relit, causing an hour-and-a-quarter delay.) An eyewitness, General Horace Parker of Grant's staff, wrote, ". . .suddenly there was a shock like that of an earthquake, accompanied by a dull, muffled roar. Then there rose two hundred feet in the air great volumes of earth in the shape of a mighty inverted cone, with forked tongues of flame darting through it like lightning playing through the clouds" (Macartney, 1953).

The explosion formed an oblong crater, at least 170 feet long, 60 to 80 feet wide, and 30 feet deep (Lykes, 1985)(see cover). Pegram's redan was obliterated, and more than 200 Confederate soldiers were killed outright.

But, as documented in Bosbyshell (1895) and other works previously cited, Union success with the "mine" was followed by dismal failure at "The Crater." By the time the battle ended at approximately 2 p.m., more than 4,000 Federal soldiers of a total attacking force of 15,000 had been killed, wounded, or captured. Many perished in "The Crater" as hundreds of poorly led troops milled about in the gigantic hole, seeking shelter from enfilading Confederate rifle and artillery fire. General Grant later wrote, "It was the saddest affair I have witnessed in the war" (Macartney, 1953).

Colonel Pleasants and the men of the 48th, relieved of taking part in the assault because of their work on the mine, were spared the ignominy that hounded many of the others involved in the debacle at "The Crater." General Burnside went on an extended leave-of-absence and never returned to active duty. Several other high-ranking officers were severely reprimanded or dismissed. Even General Meade was castigated by the Congressional Committee on the Conduct of the War (Macartney, 1953). Colonel Pleasants, though personally untarnished, was psychologically devastated by the failure of his well-laid plan. At the end of the year he resigned from the army and returned to Pottsville to resume an eventful career as a mining engineer for the Philadelphia and Reading Coal and Iron Company (see Wallace, 1987).

The 48th Pennsylvania manned its trenches facing Petersburg throughout the succeeding fall and winter months. On April 2, the regiment carried out one of the last great frontal assaults in the war, capturing Fort Mahone just southeast of the city (Figure 6).

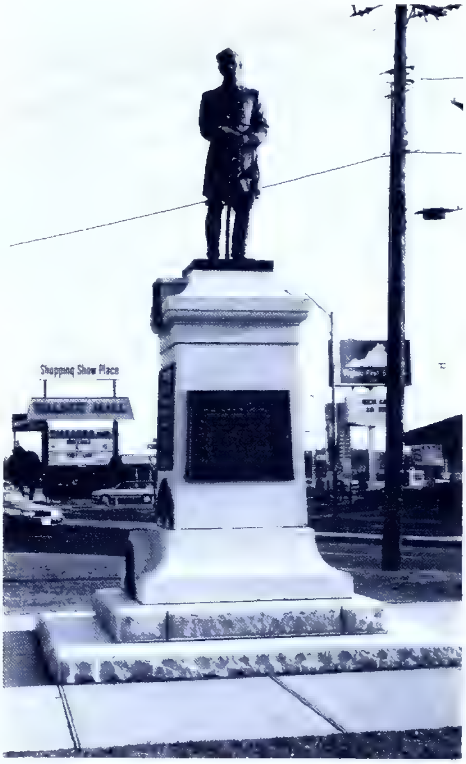

Figure 6. Monument to the 48th Pennsylvania Veteran Volunteer Regiment at the intersection of Crater Road (U.S. Route 301-460) and Sycamore Street (Alt. U.S. Route 301) in Petersburg. The bronze statue represents Colonel George W. Gowen (1840-1865), who was killed in the attack on Fort Mahone.

CONCLUSION. The nine-month-long siege at Petersburg foreshadowed in many ways the military circumstances that developed on the Western Front during World War I. In both situations, rival armies faced each other in low-relief terrain underlain by easily excavated geologic materials. The intricate trench systems constructed by the Allied and German armies in Belgium and France were exact counterparts of the maze of trenches and covered-ways created by the Union and Confederate armies at Petersburg.

And it was on the Western Front, 50 years after "The Crater," that the British perfected the use of deep underground "mines." In 1916, at the Battle of the Somme in France, they opened the "Big Push" with the successful explosion of four large mines dug in Cretaceous chalk (Keegan, 1976; Macdonald, 1989a). A year later, coal miners from Wales and the North Country carried out an even more ambitious mining project at Messines Ridge in Belgium. Eighteen mines, excavated at depths of over 70 feet in the "blue clay" of Flanders (Early Tertiary in age), were successfully exploded along a 9-mile front (Wolff, 1958; Macdonald, 1989b). The Germans were so completely stunned and demoralized by the cataclysmic blasts that the Allied troops suffered relatively few casualties in capturing the entire ridge. Henry Pleasants would have been proud!

I heartily thank C. Richard Berquist, Virginia Division of Mineral Resources; Leo Ward and John Joy, Historical Society of Schuylkill County, Pottsville, Pa.; Gerald H. Johnson, College of William and Mary, Williamsburg, Va.; Louise Arnold, U.S. Army Military History Institute, Carlisle, Pa.; John Davis, National Park Service (Petersburg National Battlefield); and Sandra Blust, Librarian of the Pennsylvania Geological Survey, for their invaluable assistance in preparing this article.

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NEW PUBLICATIONS OF THE PENNSYLVANIA GEOLOGICAL SURVEY

GROUNDWATER RESOURCES OF FAYETTE COUNTY

Groundwater Resources of Fayette County, Pennsylvania, by staff hydrogeologist Thomas A. McElroy, is a new publication in the Pennsylvania Geological Survey's practical series of Water Resource Reports. McElroy's intention in this report is to furnish new information regarding the quantity and quality of groundwater in Fayette County and to assess the impact of coal mining on these two parameters. The 57-page report is complemented by 33 figures, 14 tables, and two plates. The latter include a geologic map of the county, prepared by staff geologist James Shaulis and author McElroy, and a map showing the distribution of mined-out areas and land modified by mining operations in the county. Both maps are printed at a scale of 1:50,000.

Groundwater accrues by infiltration of water into soils and bedrock and returns to the surface through springs and at streambeds. Groundwater availability is a balance between the rate of recharge by infiltration and the rate of loss by springs, streams, and withdrawal from wells. In his report, McElroy clearly explains the mechanics of this hydrologic cycle and its control over groundwater budgets in Fayette County. He demonstrates that Fayette County contains abundant groundwater resources, which are challenging to exploit because of generally low yields. Groundwater in Fayette County also is affected in various ways by coal-mining operations. The data in this report verify that groundwater yields in Fayette County are influenced by topography, lithology, geologic structure, and in some instances, deep mining.

The bulk of the report is devoted to discussions of the hydrogeology of specific stratigraphic intervals and of the impact of coal-mining operations on groundwater quality. For each stratigraphic unit of hydrologic significance in Fayette County, McElroy provides a description of the rocks that make up the sequence, a discussion of the water-bearing properties and water quality, and a general evaluation of the aquifer. It is apparent that coal mining has caused increases in the amounts of sulfate, dissolved solids, and magnesium in water from some wells located adjacent to mines. Groundwater contamination appears limited to the vicinity of mining operations; however, McElroy provides practical suggestions regarding prudent locating of water wells and possible remedial actions for contamination.

Water Resource Report 60, **Groundwater Resources of Fayette County, Pennsylvania**, has become available at a most opportune time. Developers, planners, local, state, and federal environmental officials and scientists, coal industry representatives, and citizens of Fayette County all are currently concerned with the direction of land and resource use in the Laurel Highlands and adjacent areas in southwestern Pennsylvania. This report will be helpful to all of these parties as well as earth scientists and water well drillers or owners. The report costs $15.85 plus 96¢ state sales tax if shipped to an address in Pennsylvania, and may be ordered from the State Book Store, P. O. Box 1365, Harrisburg, PA 17105. Prepayment is required; please make checks payable to *Commonwealth of Pennsylvania*.

—C. D. Laughrey

GROUNDWATER RESOURCES OF ERIE COUNTY

More than 100,000 people, about 36 percent of the population of Erie County, depend on groundwater for domestic water supply. Much of the agricultural and industrial water needs are also met from groundwater. Although groundwater availability and quality vary greatly across the county, both quantity and quality are adequate for household supplies in most areas. Recognizing the need for better groundwater information, the Pennsylvania Geological Survey and the Water Resources Division of the U.S. Geological Survey conducted a study of this important resource. The results of this study are included in a newly published report of the Pennsylvania Geological Survey entitled **Groundwater Resources of Erie County, Pennsylvania**, which provides information about many aspects of groundwater supply, quality, and use throughout the county.

The new report reveals that glacial-outwash deposits in buried valleys and glacial-beach deposits near the Lake Erie shoreline provide yields of up to 1,000 gal/min (gallons per minute). These high-yield deposits are of very limited extent, however, occurring only along some major stream valleys and near the lake. The major potential water-quality problem in the county is high chloride content (salinity), primarily from wells in the deeper bedrock aquifers. These two examples indicate some of the types of valuable information contained in this report.

The maps and text of the report include information on the geology of the county as it relates to groundwater, distribution of major water-quality factors, and data tables and map locations for nearly 1,700 wells. Well yields are reported to range from 0.1 to 1,000 gal/min; well depths range from 9 to 405 feet. Two large maps of the county (scale 1:62,500, or about 1 inch to 1 mile) show the distribution of bedrock and the thickness of the unconsolidated (mostly glacial) deposits that overlie the bedrock.

Summary tables list the range of yields and water quality that can be expected from each of the bedrock and unconsolidated aquifers (water-bearing units) in the county. This information will be useful not only to those developing new water supplies, but also to planners for indicating areas where waste disposal or other activities could threaten existing and potential water supplies. The bedrock and surficial geologic maps, typical drillers' logs for each unit exposed in the county, and information on surface streamflows and water use will aid consultants, engineers, and environmentalists interested in the geology of the area.

Groundwater Resources of Erie County, Pennsylvania was written by David B. Richards, H. Jack McCoy, and John T. Gallaher of the U.S. Geological Survey, and is published as Pennsylvania Geological Survey Water Resource Report 62. Copies may be purchased from the State Book Store, P. O. Box 1365, Harrisburg, PA 17105; the price is $16.55 plus $1.00 state sales tax for orders shipped to a Pennsylvania address. Prepayment is required; please make checks payable to *Commonwealth of Pennsylvania*.

—H. L. Delano

EARTH SCIENCE TEACHERS' CORNER

by the Schoolhouse Mouse

Industrial Minerals—How They Are Found and Used
A New Resource Book for Earth Science Teachers

Are you aware that smuggling, hijacking, and black marketeering probably resulted from early efforts on man's part to escape burdensome taxes on a common industrial mineral, salt? Salt is absolutely essential to our existence and was once so valuable that Caesar paid his legions in salt (*salarium*, which is the origin of our word "salary"). This is one of many interesting tidbits, including tales about 20-mule teams and yarns about kitty litter, presented in Robert Bates' new book, *Industrial Minerals—How They Are Found and Used*, published by Enslow Publishers, Box 777, Hillside, NJ 07205.

Robert Bates, Professor Emeritus at Ohio State University, has written this book for young and young-at-heart students of earth sciences. With this new book, as with his past accomplishments, such as *Stone, Clay, Glass—How Building Materials Are Found and Used*, as well as *Our Modern Stone Age* (see *Pennsylvania Geology*, v. 18, no. 6, p. 7–9), he has demonstrated the gift of being able to hold our attention while explaining in common terms what industrial minerals are, how they are used, where they came from, and how they are mined. Chapter headings in his new book include "Fibers, Films, and Flakes," "Four Very Special Minerals," "Salts of the Earth," "High-Class Clays," "Phosphorus and the King of Chemicals," and "Industrial Diamonds: At the Cutting Edge." This *is not* science presented in the typical fashion of lists of tables and dry prose containing big scientific words, but is rather like Grandpa telling us a bedtime story. A glossary, starting on page 57, explains the unavoidable technical terms.

Bates' skill at intertwining human interest and science is formidable. He dishes up stories about Josiah Wedgwood, the producer of premium table china in the mid-1700's, and how he provided what was needed to grace the table of Catherine the Great of Russia. Then there is the caustic story about how Wyoming's soda ash industry put two Belgian brothers (Ernst and Alfred Solvay) out of business. You may also be astonished to learn how tiny, 15-million-year-old single-celled silica shells enhance and clarify your favorite beverage, spirited or otherwise.

Science has never been more fun! Professor Bates brings a fresh new approach to understanding the impact that industrial minerals have on our everyday lives and well-being. Because Pennsylvania makes such an important contribution to the production and manufacture of industrial minerals, we suggest that this book be added to the required reading list of all earth science students. Mineral producers might even consider donating copies to their local school libraries and science departments in an effort to promote better appreciation of their business within the community.

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Pennsylvania's First Comprehensive Atlas to Be Published This Fall

by David J. Cuff
Temple University, Department of Geography and Urban Studies

Until now, Pennsylvania, like most states, has been represented by a scattering of books and relatively modest atlases (and by special-purpose publications produced by Commonwealth agencies). Now, for the first time, Pennsylvania will have a truly comprehensive state atlas produced as a collaborative venture by Temple University, The University of Pittsburgh, and The Pennsylvania State University. The atlas is edited by five geographers from those universities: David J. Cuff and William J. Young from Temple, Edward K. Muller from Pitt, and Wilbur Zelinsky and Ronald F. Abler from Penn State.

Support for the atlas project began with a generous initial grant from five Commonwealth of Pennsylvania Departments: Commerce, Community Affairs, Education, Environmental Resources, and Transportation. In addition, the Departments of Commerce and Education contributed substantial amounts for completion of the project. Roughly two thirds of the total cost of preparing the atlas was provided by a number of foundations, by corporations across the state, and by the three universities.

The atlas will be hardbound and will be printed in five inks on 304 large pages; it will include over 1,000 maps of various sizes along with graphs, drawings, photographs, and satellite imagery. The graphics are accompanied by interpretations written by the five editors and by 30 contributing authors, three of whom are professionals working for state agencies. The major sections of the atlas are as follows:

- Introductory Essay
- Land and Resources
- Pennsylvania's Past
- Human Patterns
- Economic Activity
- Philadelphia and Pittsburgh
- Reference

The section "Land and Resources" has a number of special attractions for educators and other professionals interested in geology and the physical environment:

- Six pages devoted to geology and intended to supplement the detailed analysis in *The Geology of Pennsylvania* to be published in 1991 by the Pennsylvania Geological Survey in cooperation with the Pittsburgh Geological Society. Those six pages include a geologic road map (at a scale roughly twice that of the page-sized geologic map [Map 7] published by the Pennsylvania Geological Survey) showing selected sites from *Outstanding Scenic Geological Features of Pennsylvania* (Pennsylvania Geological Survey Environmental Geology Report 7); a review of the geologic past in Pennsylvania set in the context of the tectonic history of the earth and the movement of crustal plates; and an overview of the structural features, economic geology, and geologic hazards of Pennsylvania.
- Eight pages on the remarkable landforms of Pennsylvania, illustrated with photographs (including oblique aerial photographs), radar imagery, and block diagrams.
- Four pages on hydrology, six pages on climate, and four pages on soils.
- Sixteen pages on natural vegetation, habitats, and wildlife.
- Ten pages on the energy resources of Pennsylvania, including coal, oil and gas, hydropower, solar radiation, wind power, and biomass potential.
- Four pages on an overview of the environment, including programs of the Department of Environmental Resources.

Because of its breadth, the atlas will be a valuable reference for every Pennsylvanian. The historical section is unusually thorough, and the 25-page section on the two largest metropolitan areas in the Commonwealth is unmatched by any state atlas to date. The reference section features eight larger scale maps that cover the state, accompanied by a gazetteer listing more than 3,200 settlements and physical features.

The Atlas of Pennsylvania may be ordered from Temple University Press, 305 University Services Building, Temple Main Campus, Philadelphia, PA 19122. The price until December 31, 1989, is $90.00 plus $5.40 state sales tax for Pennsylvania residents. After December 31, the price will be $120.00 plus $7.20 state sales tax for Pennsylvania residents. The shipping charge is $5.00 for the first copy ordered and $2.50 for each additional copy. Please make checks payable to *Temple University Press*.

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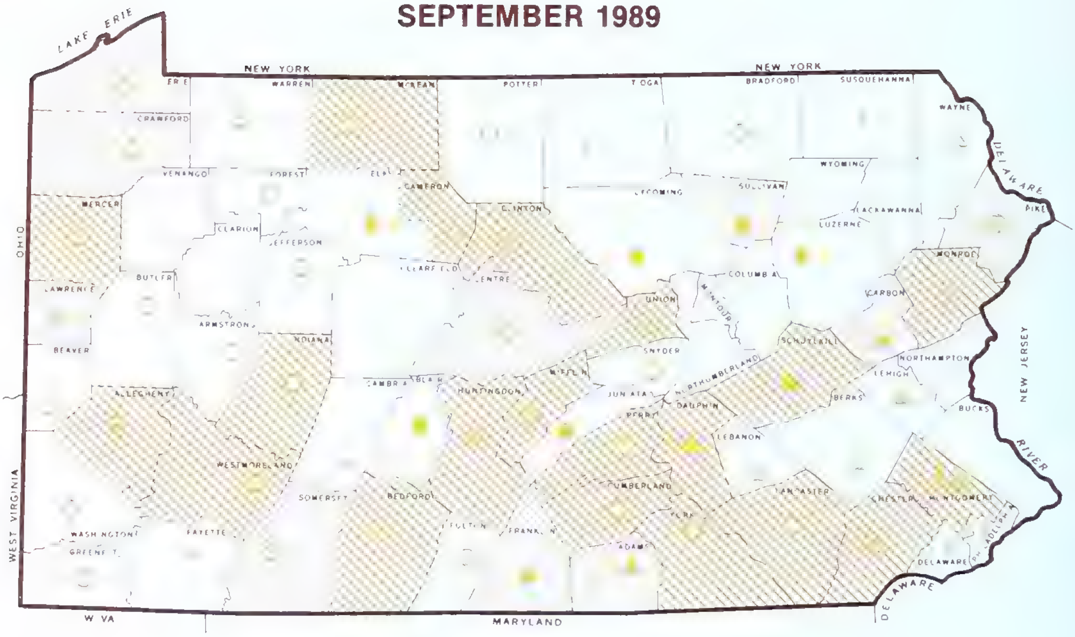
GROUNDWATER-RESOURCE MAPPING

GROUNDWATER LEVELS
FOR
SEPTEMBER 1989



EXPLANATION

○ Above last year
● Below last year
Observation well

△ Above last year
▲ Below last year
Observation well equipped with data-collection platform

x No data

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PENNSYLVANIA GEOLOGY

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NSYLVANIA GEOLOGICAL SURVEY VOL. 20/6

COMMONWEALTH OF PENNSYLVANIA
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ON THE COVER: Stack of Franklin Anthracite Steam Furnace on Old Furnace Road, about 1 mile west of Mausdale, Valley Township, Montour County. Erected in 1846 during the early days of the anthracite-iron industry, Franklin was one of many furnaces in the North Branch Susquehanna River region that made cast iron bars and implements using "Clinton fossil-ore" from Montour Ridge, "hard coal" from the Northern Anthracite field, and local Silurian-Devonian limestone. Photograph by J. D. Inners.

PENNSYLVANIA GEOLOGY is published bimonthly by the Bureau of Topographic and Geologic Survey, Pennsylvania Department of Environmental Resources, P. O. Box 2357, Harrisburg, Pennsylvania 17105.

Editors, Christine M. Dodge and Donald M. Hoskins.

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VOL. 20, NO. 6 **DECEMBER 1989**

MAR 01 1990

Developing a National Energy Strategy

Our nation is again engaged in developing a National Energy Strategy. The U.S. Department of Energy is seeking to identify the major issues and is seeking recommended solutions to current and anticipated problems of providing energy for our industrial needs and our rapidly growing population. This strategy will take into account many of the known and recently recognized environmental effects that may be occurring throughout our nation. Contributing to some of these changes is the use of Pennsylvania's abundant fossil-fuel (coal, natural gas, and petroleum) resources.

No strategy will be successful unless it is supported by hard facts—basic data on energy resources. The National Energy Strategy will undoubtedly contain recommendations for "frontier" scientific research, including the understanding of the geology of fossil fuels. Yet, regardless of how sophisticated such research is, it is data driven.

In 1988 the Pennsylvania Energy Office published its "Energy Policy for Pennsylvania," which indicates that the Commonwealth has a demonstrated reserve base of 20 billion tons of bituminous coal. A recently issued report by the U.S. Geological Survey, published in cooperation with the Geological Surveys of Kentucky, Virginia, and West Virginia, shows that newly developed criteria including land use and other technical restrictions may reduce earlier estimates of coal availability by up to 40 percent! This vast improvement in the accuracy of resource estimates was only possible through the analysis of sufficient site-specific geologic data (coupled with accurate geologic mapping) collected by these Surveys.

In any national energy policy, the data needed to substantiate solutions concerning the use of fossil fuels start with the resource itself—its geographical location and its physical and geochemical characteristics. The collection and analysis of geologic and geochemical data on fossil fuels are not regarded as "frontier" science activities, but, though mundane, such work must continue and must be duly accommodated in the National Energy Strategy. Failure to support the growing need to collect and analyze basic data on fossil fuels will severely reduce the effectiveness of the forthcoming National Energy Strategy and its recommended solutions.

Donald M Hoskins

Donald M. Hoskins
State Geologist

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DOCUMENTS SECTION

Fossil Fish Locality in the Catskill Formation (Upper Devonian) near Port Matilda, Centre County, Pennsylvania

by Albert J. Robb III and Clifford A. Cuffey
412 Deike Building
Pennsylvania State University
University Park, PA 16802

INTRODUCTION

In a large roadcut along U.S. Route 322, 2.4 to 2.6 miles west of Port Matilda, Centre County (Figure 1), approximately 320 feet of the Upper Devonian Catskill Formation is exposed (Figure 2). The locality is significant because it contains abundant fossils of placoderm and crossopterygian fish; brachiopods, pelecypods, plants, and

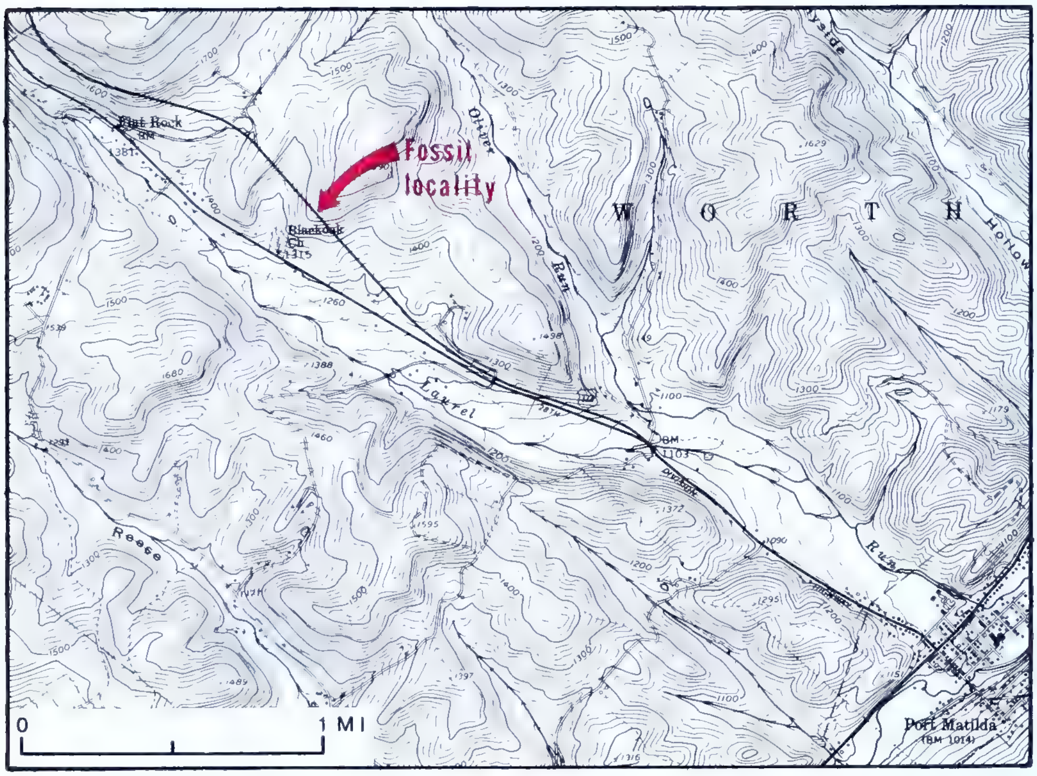

Figure 1. Map showing the location of the Port Matilda fossil fish locality.

trace fossils are also present (Table 1). Easy and profitable collecting can be accomplished by examining rubble at the bottom of the vertical face. *Extreme caution should be observed at this locality due to highway traffic and falling rock.*

STRATIGRAPHY AND PALEOENVIRONMENTS

Overall, the Catskill Formation exposed at the Port Matilda roadcut is part of a large delta complex built westward into the Appalachian seaway during the Late Devonian (Williams, 1985; Williams and Slingerland, 1985). Within the section are three distinct lithofacies representing deposition in four distinct paleoenvironments, each having a unique fossil assemblage. The most abundant lithofacies at this roadcut is red mudstone containing thin sandstone interbeds. This lithofacies was deposited in three distinct paleoenvironments. First, some beds contain fossils of lingulid brachiopods, pelecypods, and indeterminate burrows. Based on comparison with similar layers described by Gordon and Knox (1989) from New York State, the authors conclude that these rocks were deposited under brackish water in a very nearshore setting. Second, other beds contain plant root casts and impressions of plant foliage, implying deposition in marshes (Williams and Slingerland, 1985). Third, additional beds contain fossils of fish known to inhabit freshwater environments (Denison, 1951), indicating deposition in streams and lakes.

Interbedded with the red mudstones and thin sandstones are two other lithofacies. One consists of greenish-gray to tannish-gray mudstone and sandstone; rocks of this lithofacies contain lingulid brachiopods and indeterminate burrows. They were probably deposited under brackish water in a very nearshore setting such as that described by Gordon and Knox (1989) for similar layers in New York State. The other lithofacies, composed of thick red sandstone exhibiting cross-bedding, represents channel deposits that formed in estuarine and fluvial environments (Williams and Slingerland, 1985).

PALEONTOLOGY

All of the fossils found at the Port Matilda roadcut (Table 1) occur in several thin layers scattered throughout the section (Figure 2). The fish remains are concentrated in rich coquinoid layers within the red mudstone and thin interbedded sandstone lithofacies, both in the mudstone and the sandstone layers. Here, the plates, scales, and teeth are mostly preserved as bone, but some molds are present. Rarely, fish remains occur as isolated, poorly preserved fragments in other lithofacies. The brachiopod *Lingula* and the pelecypod *Parallelodon* occur either together or separately, in thin layers, where

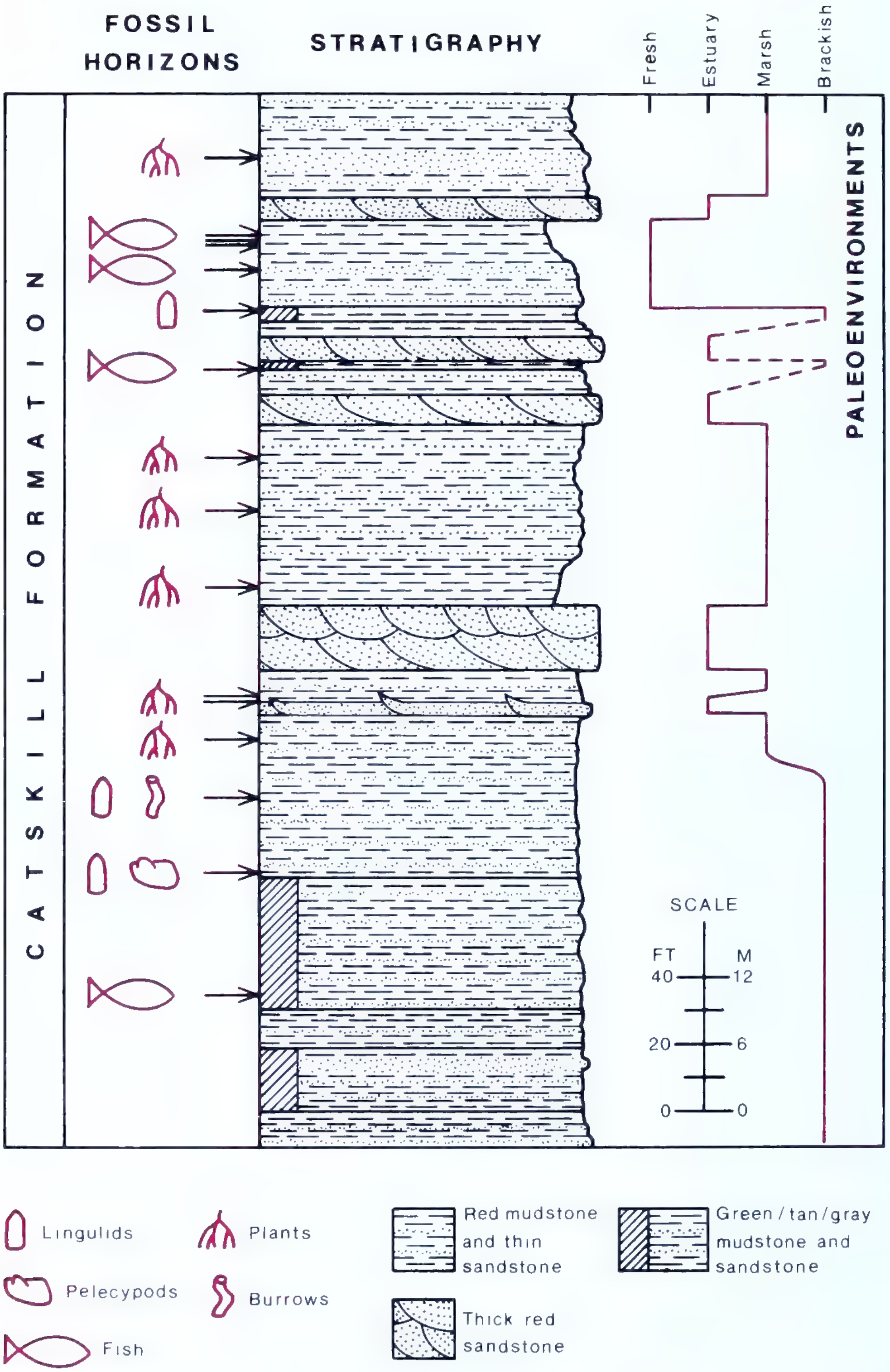

Figure 2. Stratigraphic column illustrating the rocks exposed and the fossil horizons present at the Port Matilda fossil fish locality.

Table 1. ***Faunal List for the Catskill Formation at the Port Matilda Roadcut***

VERTEBRATA
  Placodermi
    Bothriolepis cf. *B. nitida* (Leidy)
    Head shield indeterminate
  Chondrichthyes(?)
    Spines indeterminate
  Osteichthyes (Crossopterygii)
    Litoptychius sp.

INVERTEBRATA
  Brachiopoda
    Lingula ligea Hall
    L. spatulata Vanuxem

INVERTEBRATA *(continued)*
  Pelecypoda
    Parallelodon chemungensis (Hall)
    Indeterminate fragments

PLANTAE
  Root casts
  Foliage

ICHNOFOSSILS
  Burrows indeterminate

they are abundant and in some places associated with indeterminate burrows. Most commonly, they are preserved as molds; however, some specimens of *Lingula* still retain the original shell material. Plant remains are scattered throughout the section, principally as isolated roots or foliage. The most significant types of fossils are illustrated in Figure 3.

The most abundant fish remains are thin (2 to 5 mm) fragments of the headshields and armored pectoral fins of the placoderm *Bothriolepis* cf. *B. nitida* (Leidy) (Figure 4). This placoderm possessed a dorsoventrally flattened (vertically compressed) headshield, which armored the anterior portion of the fish's body; the pectoral fins were attached to the headshield. The exterior of the bony armor of the headshield exhibits two distinct types of ornamentation. Some portions have tubercles arranged in a reticulate pattern, giving the surfaces a netlike appearance; other portions are ornamented with a sinuous vermiculating pattern, giving the surfaces a winding furrowed appearance. The interior of the bony armor is virtually smooth. The remaining portions of the fish *Bothriolepis* are known to have little or no armor or scales, and thus are not preserved at this locality.

Also found at this locality, though much rarer, are the teeth and scales of the crossopterygian fish *Litoptychius* sp. The teeth taper, are oval in cross section, and range from 10 to 35 mm in length. Their basal portion exhibits longitudinal furrows, whereas their upper halves are smooth. The scales of *Litoptychius* sp. are cycloidal (subcircular); the internal sides of the scales are nearly smooth, whereas the external sides are ornamented with fine tubercles arranged in fanlike patterned rows. These scales average 20 mm in diameter and can be as thick as 3 mm.

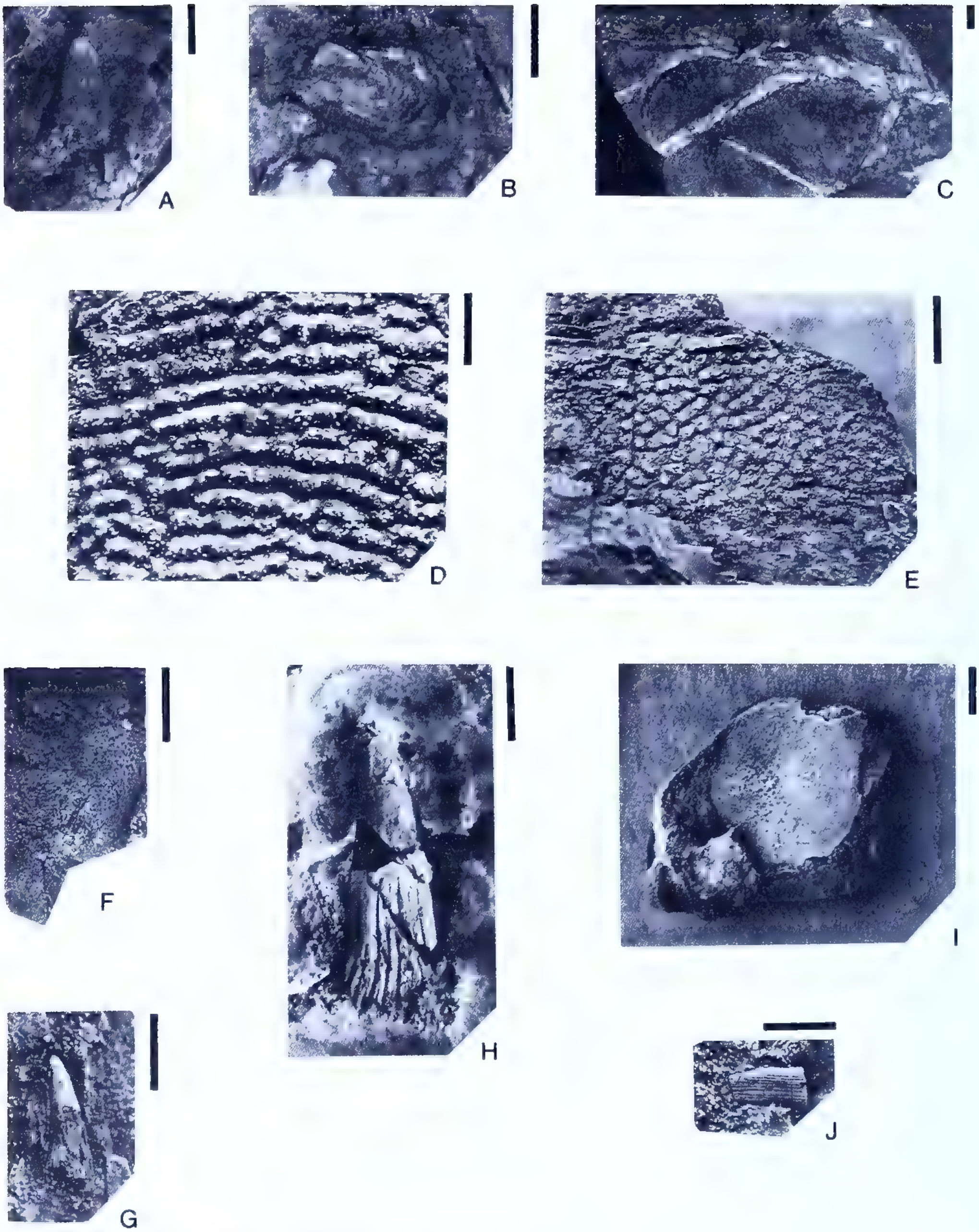

Figure 3. A. Brachial valve of *Lingula ligea*. B. Left valve of *Parallelodon chemungensis*. C. Root cast. D. Exterior surface of *Bothriolepis* cf. *B. nitida* bony headshield armor; sinuous vermiculating ornament (winding furrowed appearance). E. Exterior surface of *Bothriolepis* cf. *B. nitida* bony headshield armor; reticulate ornament (netlike appearance). F. Interior surface of *Bothriolepis* cf. *B. nitida* bony headshield armor. G. Small-sized tooth of *Litoptychius* sp. H. Large-sized tooth of *Litoptychius* sp. I. Internal surface of *Litoptychius* sp. scale. J. Indeterminate spine fragment; Class Chondrichthyes. All scale bars are 5 mm in length.

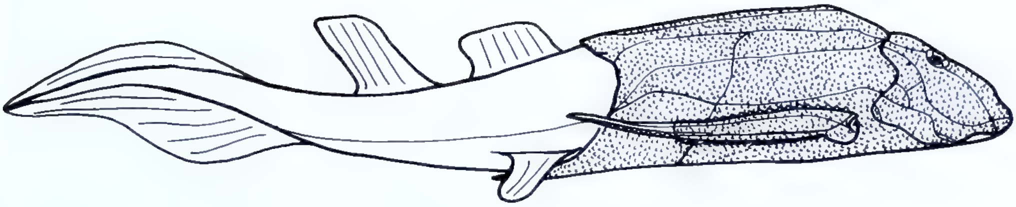

Figure 4. Reconstruction of *Bothriolepis* (adapted from Stensiö, 1969). In life, the fish was approximately 50 cm long.

Several indeterminate spines have also been recovered, which are tentatively assigned to the class Chondrichthyes. Furthermore, fragments of a very large and thick-boned (30 mm) headshield have been collected; they are tentatively assigned to the class Placodermi. Finally, unidentifiable fish bone fragments are commonly recovered. Certainly, many of these are portions of *Bothriolepis* and *Litoptychius*, but some may belong to other fish taxa as well.

FISH PALEOECOLOGY

As described by Denison (1951), *Bothriolepis* inhabited fresh water. It followed a nektobenthonic (i.e., a free-swimming but near-bottom) lifestyle. A freshwater environment is consistent with the data collected from Port Matilda; specifically, the fish do not occur in the same beds with the brackish-water invertebrates. Furthermore, nearby occurrences of *Bothriolepis* (in other layers within the Catskill Formation) are in rocks interpreted by Williams and Slingerland (1985) as fluvial, and thus are freshwater deposits. Because the remains of *Litoptychius* are found in the *Bothriolepis*-bearing beds, the authors conclude that it also inhabited fresh water. The coquina layers probably represent accumulations of large numbers of fish in small, localized areas either in fluvial or lacustrine environments. Some scattered, poorly preserved fish remains that occur at other horizons probably represent isolated individuals preserved in the same freshwater environment, whereas other remains suggest that isolated individuals were washed downstream into brackish-water environments.

We thank William J. DiBrino of Tampa, Florida, and Jennifer J. Criss of Bethel Park, Pennsylvania, for their help in conducting the field work for this paper, and Paul D. Zell of State College, Pennsylvania, for his help in preparing the specimens for photographing. Helpful review comments by Jon D. Inners and John A. Harper of the Pennsylvania Geological Survey improved the manuscript.

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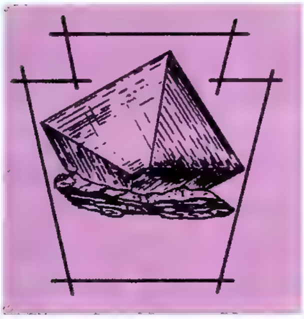
Newly Discovered Mineral Named for Pennsylvania Geologist

Charles B. Sclar, professor of geological sciences at Lehigh University in Bethlehem, has recently received the honor of having a mineral, sclarite, named for him. This mineral was found in one of the handful of districts that have names instantly recognizable to many mineralogists worldwide—Franklin and Sterling Hill, New Jersey. The area is in the northern part of that state, about 30 miles east-northeast of the Delaware Water Gap. Professor Sclar received the honor in recognition of his research on the origin of the zinc ores in that district.

Sclarite, a carbonate of zinc having the chemical formula $Zn_7(CO_3)_2(OH)_{10}$, was described and named by Pete J. Dunn of the Smithsonian Institution National Museum of Natural History in Washington, D. C., and Joel Grice of the National Museum of Natural Science in Ottawa, Canada. It is reported to be structurally similar to loseyite, $(Mn,Zn)_7(CO_3)_2(OH)_{10}$, another mineral that was discovered at Franklin 60 years earlier.



EARTH SCIENCE TEACHERS' CORNER

by William E. Kochanov

The Earth Has a History

Imagine trying to explain the concept of geologic time to junior and senior high school students. What sort of examples could an instructor use?

An excellent film, emphasizing the concept of geologic time, has been prepared by the Geological Society of America. In the film, a modern stream environment is used as an example to explain two principles that demonstrate geologic history. The first is original horizontality (sedimentary layers accumulate horizontally), and the second is superposition (the layer of rocks on the bottom had to be deposited first, and therefore is the oldest layer). This film characterizes the sequential layering of sediments and illustrates how one may view the layers in a three-dimensional framework. The film demonstrates how a student can decipher the major features of the geologic history of an area. By using a combination of a modern-day example from South Boulder Creek, outcrop examples from the Flatiron Mountains (both located in Colorado), and graphic representations of the depositional sequences, the student is kept geographically oriented while, at the same time, key concepts are reinforced.

The examples used in the film may be applied to similar streams and bedrock occurrences in Pennsylvania. Most of the rocks exposed in Pennsylvania are sedimentary rocks. The sandstone, shale, and limestone layers provide a sequential record of events that have occurred in Pennsylvania over a specific period of time. The way in which layers of rocks are arranged tells a story of ancient environments and forces that have acted upon those environments. By examining and recording the sedimentary features within a rock sequence, it is possible to decipher the hidden story within the rocks and to better understand the geologic formation and evolution of our state.

Educators may use the film to help students, in a 20-minute period, understand how changes of the earth's surface occur over a period of time. The film also introduces the student to earth processes that are continually at work.

The film, entitled "The Earth Has a History," was developed by Dr. Allison R. Palmer. The clear and easy-to-understand manner of presentation makes the film ideal for incorporation into the beginning phase of an earth science curriculum or for a biology section on the record of life on the earth. The film is available on VHS video or 16-mm film. It may be purchased from the Geological Society of America, P. O. Box 9140, Boulder, CO 80301, at a cost of $25.00 for the VHS video (order EVS001) or $200.00 for the 16-mm film (order EFS001). A limited number of the VHS video films are available for loan through the Pennsylvania Geological Survey library, P. O. Box 2357, Harrisburg, PA 17105, telephone 717-783-8077.

NEW PUBLICATIONS

MAP OF RADIUM IN GROUNDWATER IN SOUTHEASTERN PENNSYLVANIA

In response to public-health concerns raised several years ago by the discovery of elevated levels of radium in three public water supplies that utilize groundwater from the Chickies Formation of southeastern Pennsylvania, the U.S. Geological Survey (USGS) has published a map that shows the location of that formation and the initial results of a study that the USGS conducted in cooperation with the Pennsylvania Geological Survey. This map, at a scale of 1:250,000, was first made public in 1987 but, until recently, has been available only by inspection at the Malvern office of the USGS. Of 56 wells tested, 24 contained radium in excess of the maximum level of 5 pCi/L (picocuries per liter) set by the U.S. Environmental Protection Agency for public water supplies. These are indicated by different symbols on the map, which shows the locations of all 56 wells.

The Chickies Formation, a quartzite, is found in a discontinuous belt that extends from west of Morrisville, Bucks County, to east of New Oxford, Adams County. Most of the wells identified as having levels above 5 pCi/L are in Chester and eastern Lancaster Counties.

The map, entitled **Map Showing Radium Concentrations in Ground Water of the Chickies Formation, Southeastern Pennsylvania, 1986-87**, by L. DeWayne Cecil, may be obtained by requesting Open-File Report 87-232 from the U.S. Geological Survey, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225; enclose $2.25 for paper copy or $1.50 for microfiche, payable to *Department of the Interior—USGS*.

A complete report of the continuing investigation, including detailed chemical and radiological analyses, will be published in the near future.

—J. H. Barnes

GROUNDWATER RESOURCES OF THE CHEMUNG RIVER BASIN

The Susquehanna River Basin Commission has recently issued Publication 115, entitled **Groundwater Resources of the Chemung River Basin, New York and Pennsylvania**, by Larry E. Taylor. This report contains a discussion of groundwater quality, quantity, use, and flow systems in the Chemung River basin. The basin is located within the northern portions of Bradford, Tioga, and Potter Counties in Pennsylvania. The effects of glaciation are an important factor in the hydrogeology of the area. The most productive and important aquifers in the area are composed of stratified drift. The median yield for municipal and industrial wells in these unconsolidated glacial deposits is 300 gallons per minute. However, the same factors that make these rocks productive aquifers also make them susceptible to contamination.

High concentrations of iron and manganese are the most widespread naturally occurring water-quality problems. High barium concentrations are not as widespread, but do occur in about 7 percent of the wells sampled in the Chemung River basin. Most of these occur in bedrock wells in or near large valleys. The author surmises that the high barium concentrations are the result of dilution of brines, which are present at shallow depths in the large valleys. The shallow depths of these brines are thought to be the result of glacial erosion of the valley bottoms.

For further information concerning this publication, contact the Susquehanna River Basin Commission, 1721 North Front Street, Harrisburg, PA 17102, telephone 717-238-0422.

—D. Yannacci

GROUNDWATER DATA FOR CHESTER COUNTY

The U.S. Geological Survey (USGS) has published an open-file report containing basic groundwater data for Chester County. This report, entitled **Selected Ground-Water Data, Chester County, Pennsylvania**, was prepared in cooperation with the Chester County Water Resources Authority and is authored by Ronald A. Sloto of the USGS, Water Resources Division. Open-File Report 87-217 contains general construction, production, and location information for 3,010 wells and 32 springs in the county. Water-level records for 48 observation wells and the results of chemical analyses for water from several hundred wells and springs were also compiled for this report. The information is presented in numerous tables; a geologic map (scale 1:50,000) showing well and spring locations is also included.

The report may be purchased from the U.S. Geological Survey, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225; enclose $39.75 for paper copy and $5.50 for microfiche. Please make checks payable to *Department of the Interior—USGS*. The report may also be examined in the library of the Pennsylvania Geological Survey, Room 916, Executive House, 101 South Second Street, Harrisburg; in the USGS subdistrict office, 111 Great Valley Parkway, Malvern; and in the offices of the Chester County Water Resources Authority, 3rd Floor, Dague Building, West Chester.

—D. Yannacci

New Staff of the Pennsylvania Geological Survey

Jody R. Smith

Jody Smith joined the staff of the Survey in May 1989. In her position as Clerk Typist, Jody performs secretarial duties for the Geologic Mapping Division and the Mineral Resources Division. Jody transferred to the Department of Environmental Resources after 5 years as a Data Recording Machine Operator in the Bureau of Data Reduction in the Department of Revenue. Prior to that, she spent 2½ years as an office clerk at Rite-Aid Corporation in Shiremanstown.

A native of central Pennsylvania, Jody graduated from Cumberland Valley High School in 1976, and she earned a B.A. in Christian Education from Messiah College in 1981. Jody presently resides in Boiling Springs with her husband, Michael.

Patricia F. Buis

Pat Buis joined the Coal Section of the Geologic Mapping Division of the Survey as a geologist in May 1989. She has been assigned to phase two of the National Coal Resources Data System (NCRDS), a computer data system developed by the U.S. Geological Survey to facilitate coal-resource calculations for the nation. Pat will study the chemistry of bituminous coals in Pennsylvania; she will supplement available data, run statistical analyses, and produce tables and maps of coal characteristics.

Pat has a strong geochemistry background. From 1988 to 1989, she worked for Pennrun Corporation in Pittsburgh, performing chemical analyses of toxic metals. In 1987, Pat received a Ph.D. in geology from the University of Pittsburgh. Her dissertation was on the geochemistry of the carbonate country rock around the Sterling Hill ore deposit in Ogdensburg, New Jersey. While at the university, Pat worked as a microcomputer laboratory assistant and as a teaching assistant in Mineralogy, Economic Geology, and Geochemistry laboratories. Pat obtained her M.A. in geology in 1983 from Queens College, City University of New York. She studied fluorite bands in the Sterling Hill ore deposit for her thesis work and was an adjunct lecturer in Physical Geology and Structural Geology laboratories. Pat also attended Rutgers University in New Jersey, where she earned a B.A. in geology in 1976.

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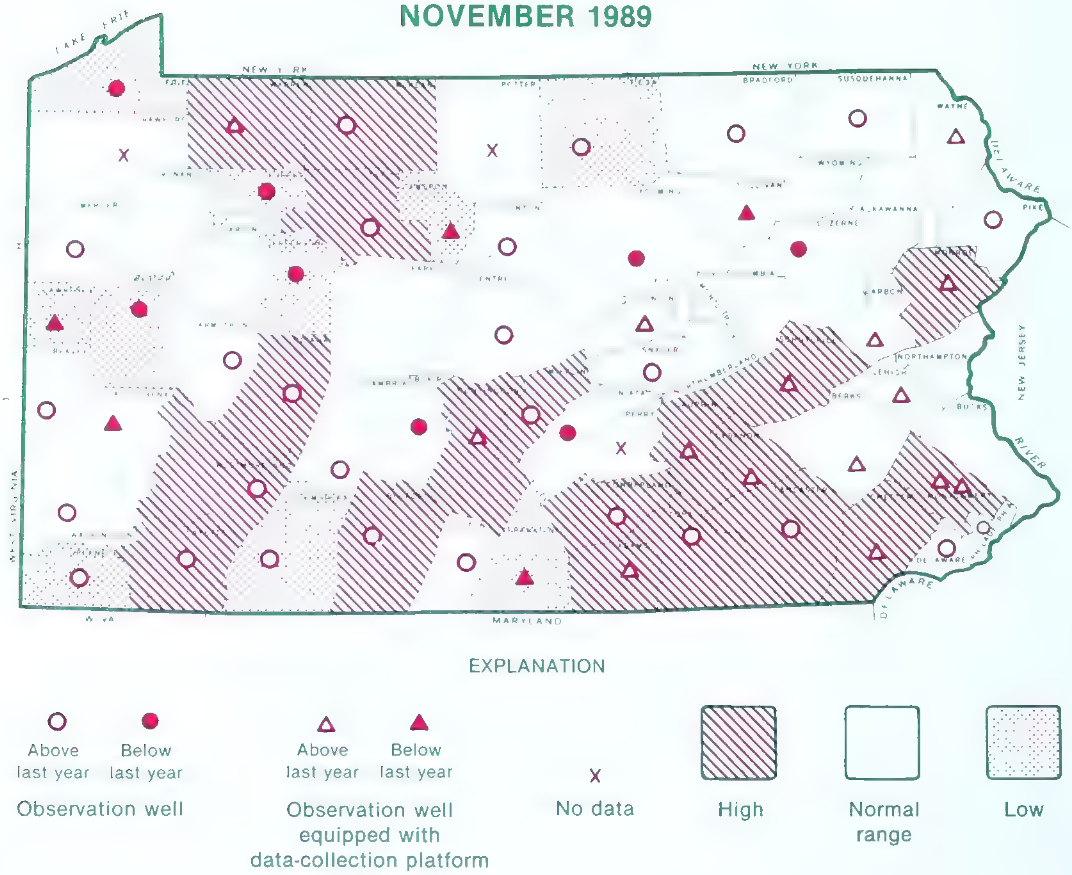

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ON THE COVER: Unusually well developed ice "dunes" near the lighthouse at Presque Isle State Park, Lake Erie. The "dunes" form in association with pressure ridges in a shelf of lake ice attached to the shore. Wave surge forces water up through cracks in the ice, and it freezes on the surface. Under special conditions, repetition of this process and addition of freezing spray produces a volcano-like structure of layered ice. The ice surface is steep, slippery, and fragile, making close examination of the dunes extremely hazardous. Visitors should admire them from the safety of the beach. This photograph was taken by Helen L. Delano in January 1981, and will be included in an upcoming geologic guide for Presque Isle State Park to be published by the Pennsylvania Geological Survey.

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The Unfortunate Rewards of Success— Fossil Collecting at Swatara Gap Site to End

The fossil-collecting locality at picturesque Swatara Gap, renowned throughout Pennsylvania, the United States, and beyond, is likely to be removed from public access. Our bureau has been asked to notify readers of this journal that the Pennsylvania Department of Transportation (PennDOT) is strongly considering the closing of the site to the public.

Swatara Gap has been a favored and well-used collecting locality for over 50 years because of the abundance of the small trilobite *Cryptolithus* and because it is a locality for collecting the very rare Ordovician-age starfish *Protasterina*. The ease of access to this site (it is on public property, a PennDOT right-of-way) and the abundance and variety of fossils there have made the locality famous among researchers, serious and amateur collectors, school groups, and casual visitors.

But our success in advertising the locality as a recommended collecting site has led to its overuse and to extensive removal of rock to the point that the safety of the berm supporting the southbound lane of Interstate 81, which crosses over the collecting site, may be threatened if further collecting is allowed.

We urge that all who plan to visit the site use restraint and caution. If collecting remains allowed, it should be done only from loose material that has naturally weathered; do not "quarry" the outcrops. If the locality becomes posted, do not attempt to ignore the warnings. The safety of the highway traffic above is more important than the collection of fossils.

We will work with PennDOT to try to arrange that the locality remains available to researchers and for academic purposes. We will need your support and patience in this matter.

Removal of localities from public access has occurred in the past and will occur in the future as more and more people who are interested in natural objects take advantage of available sites that have been made publicly known. Many of these sites are on private property and have been freely opened to the public by the property owners. Visitors to these sites should conduct themselves as guests. Whether the sites are on public or private property, collectors should recognize that they have a responsibility to ensure that localities are not abused to the point that they become unavailable for public use.

Perhaps it is time to consider whether special localities containing abundant or unusual fossils or minerals could become part of some system of natural sites to be made available to the public for educational and recreational purposes. If you have comments on this subject, we would appreciate hearing from you.

Donald M. Hoskins

Donald M. Hoskins
State Geologist

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IN MEMORIAM

Tracy V. Buckwalter (1918–1989)

Dr. Tracy V. Buckwalter, Professor Emeritus of the Geography and Earth Science Department at Clarion University of Pennsylvania, died at his home in Shippenville, August 15, 1989. He was 71 years old. At the time of his retirement in 1983, he had spent 34 years teaching geology, first at the University of Pittsburgh from 1949 to 1965, and then at Clarion State College, as it was formerly known, from 1965 to 1983. From 1972 to 1979 he chaired the department at Clarion.

Trained as a "hard-rock" geologist, "Buck," as he was known to his colleagues, did extensive field work in eastern Pennsylvania in the Reading Prong as a cooperating geologist with the Pennsylvania Geological Survey. In a decade of intensive summers' field work (1951–60), Buck examined the Reading Prong rocks from Womelsdorf to the Macungie area. A conscientious and energetic field geologist of the "old school," he proved well suited to the task. The 10 summers and much laboratory work led to 10 significant papers on the geology of the area, four of which were published by the Pennsylvania Geological Survey.

In an area of poor exposure, he was precluded from making facile generalizations. As a result, his field work was meticulous. Initially Buck's field work vindicated the classic interpretation of the Reading Prong as a rooted anticline. Geophysical investigations and changed paradigms of orogenic processes in the decades following his work led to the collapse of the anticlinal interpretation. However, modern recognition of the rootless characteristics of the Reading Prong in no way invalidated his mapping. Buck's relentless dedication to recording the data as it appeared in the field, unbiased by the accepted interpretation of that era, makes his data as valid today as ever.

In addition to his academic and Survey activities, Dr. Buckwalter at various times was a geologist for the U.S. Army Corps of Engineers, the U.S. Atomic Energy Commission, and the Texas Company, and was also a private consultant.

Dr. Buckwalter received his academic degrees—Bachelor of Science (1940), Master of Science (1946), and Doctorate (1950)—from the University of Michigan, where he had a predoctoral fellowship from the National Research Council from 1946 to 1949.

Buck was an enthusiastic member of the Field Conference of Pennsylvania Geologists and hardly missed a field trip since its inception, even attending a few after suffering a stroke in 1980. He was a dedicated teacher and practitioner of "old-fashioned" foot-slogging geologic mapping, utilizing his mapping for the Pennsylvania Geological Survey to educate University of Pittsburgh graduate students, who often accompanied him during the summertime. He also served as president of the Pittsburgh Geological Society and was a member of the North Appalachian Geological Society. His students, academic colleagues, and Survey friends remember his gentleness, quiet humor, and widely ranging and perceptive mind. We are all diminished by his death.

by Theodore F. Buckwalter

The Importance of Serendipity: Dorcie Calhoun and the Leidy Gas Field

by John A. Harper
Pennsylvania Geological Survey

Every now and then we hear about an actual incident so outrageous that a fiction writer would be ashamed to admit that he had written such a story. Luck, or serendipity, typically has a great deal to do with such tales. The story of how Dorcie Calhoun discovered natural gas in the Ridgeley Sandstone in the Leidy field, and in so doing ushered in a new age of deep drilling in the Appalachian basin, is just such a tale. It may have been embellished a bit in the many retellings, but it is nonetheless a true story worth repeating.

The Leidy field is situated in Clinton and Potter Counties in north-central Pennsylvania (Figure 1). It consists of one pool in the Upper Devonian Lock Haven Formation (not shown) and five pools in the Lower Devonian Ridgeley Sandstone, all of which occur on the flanks

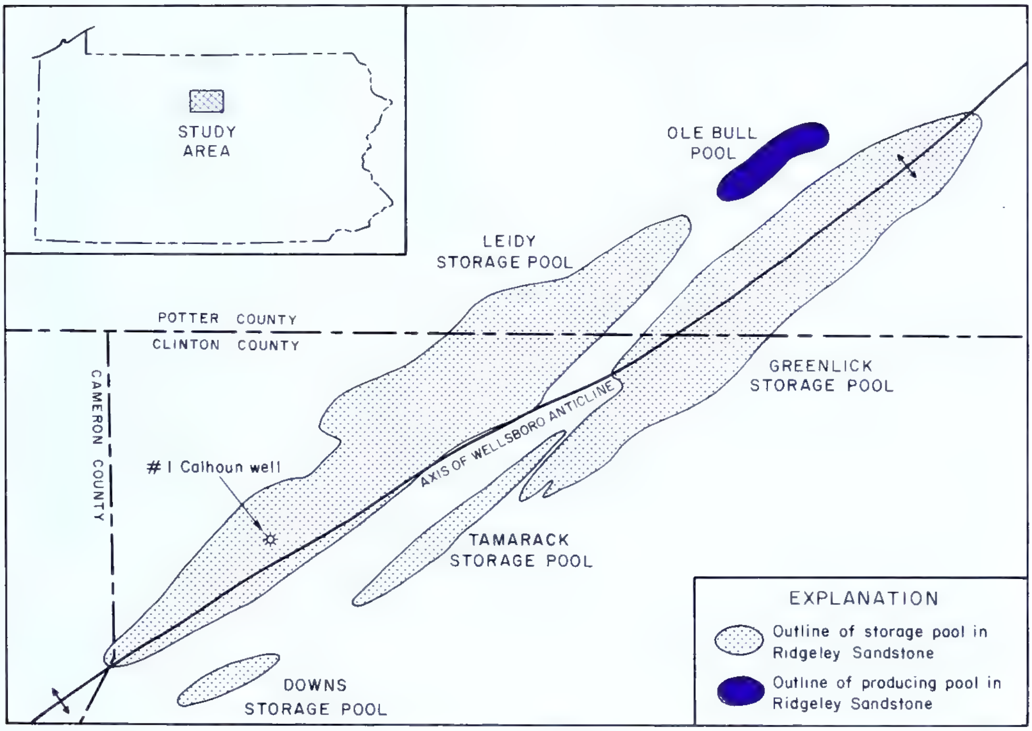

Figure 1. Map showing the location of Ridgeley gas pools in the Leidy field and the surface axis of the Wellsboro anticline. The gas well symbol shows the location of Dorcie Calhoun's discovery well.

of the Wellsboro anticline. The field had estimated ultimate recoverable reserves in excess of 175 billion cubic feet of gas; the pools are largely depleted now, however, and most of the field is being used to store gas produced elsewhere.

The Leidy field was discovered in 1864 by completion of a gas well drilled into the Lock Haven Formation near Hammersley Fork, Clinton County. The field is best known, however, for its production of natural gas from the Ridgeley Sandstone. Before 1930, the Ridgeley ("Oriskany" of drillers and some authors) was considered to be prohibitively deep throughout most of western and north-central Pennsylvania. At that time, only 36 wells had penetrated to the Ridgeley in the state, without much success (Fettke, 1950). Natural gas was eventually discovered in the Ridgeley in 1930 in south-central New York and in Tioga County, Pennsylvania. This led Stanley Cathcart of the Pennsylvania Geological Survey to research and publish a report on the geology of potential oil and gas deposits in north-central Pennsylvania (Cathcart, 1934) that became something of a bible for companies actively seeking Ridgeley gas. Throughout the 1930's and 1940's, more than 550 "deep" wells were drilled in Pennsylvania in the search for the elusive resource (Fettke, 1950). Only a few fields were discovered during this time, however, and by 1949 drilling was in a declining phase.

Despite stories to the contrary by the popular press (e.g., Davidson, 1951), many geologists thought that the Leidy area had high potential for gas production. By the late 1940's, New York State Natural Gas (now Consolidated Natural Gas Corporation) had acquired leases on about 11,000 acres on the Wellsboro anticline in the vicinity of Leidy (Ingham, 1954). The company was well aware that, as a result of pinchout to the north and west, the Ridgeley Sandstone was absent in a large area of northern Pennsylvania and southern New York. In addition, the sandstone in all of the wells drilled on the Wellsboro anticline in Tioga County, northeast of Leidy, had been too tightly cemented to produce more than a show of gas. As a result, New York State Natural Gas considered the anticline in the Leidy area too risky to explore without further evaluation. However, these concerns meant little to one local citizen whose name has become legend in the oil and gas industry.

As the story goes, Dorcie Calhoun (Figure 2) had "known" that there was gas on the family farm near Leidy since he was a boy. He had even seen it bubbling out of nearby Kettle Creek, where he liked to fish. Dorcie spent years telling folks in the vicinity that there was gas under the Leidy area, but very few people took him seriously. Then in 1949, with the help of Cathcart's report, he finally managed to convince the editor and publisher of the local newspaper to back him in his venture. This "stamp of approval" from a well-respected member of the community, plus the knowledge that New York State Natural Gas thought enough of the area to lease large tracts of land, suddenly made Dorcie's ideas tenable to the citizens of Clinton County, and other potential investors in the area ran to Dorcie with their share of the stake. After forming the Leidy Prospecting Company, Dorcie bought an old dilapidated drilling rig used in the shallow oil fields around Bradford, McKean County, and hauled it back to Leidy. As luck would have it, it was raining hard when the equipment caravan arrived, and the lead truck got stuck in the mud little more than a few hundred feet up the road to the top of the mountain, the site that had been chosen for the first well. When it became apparent

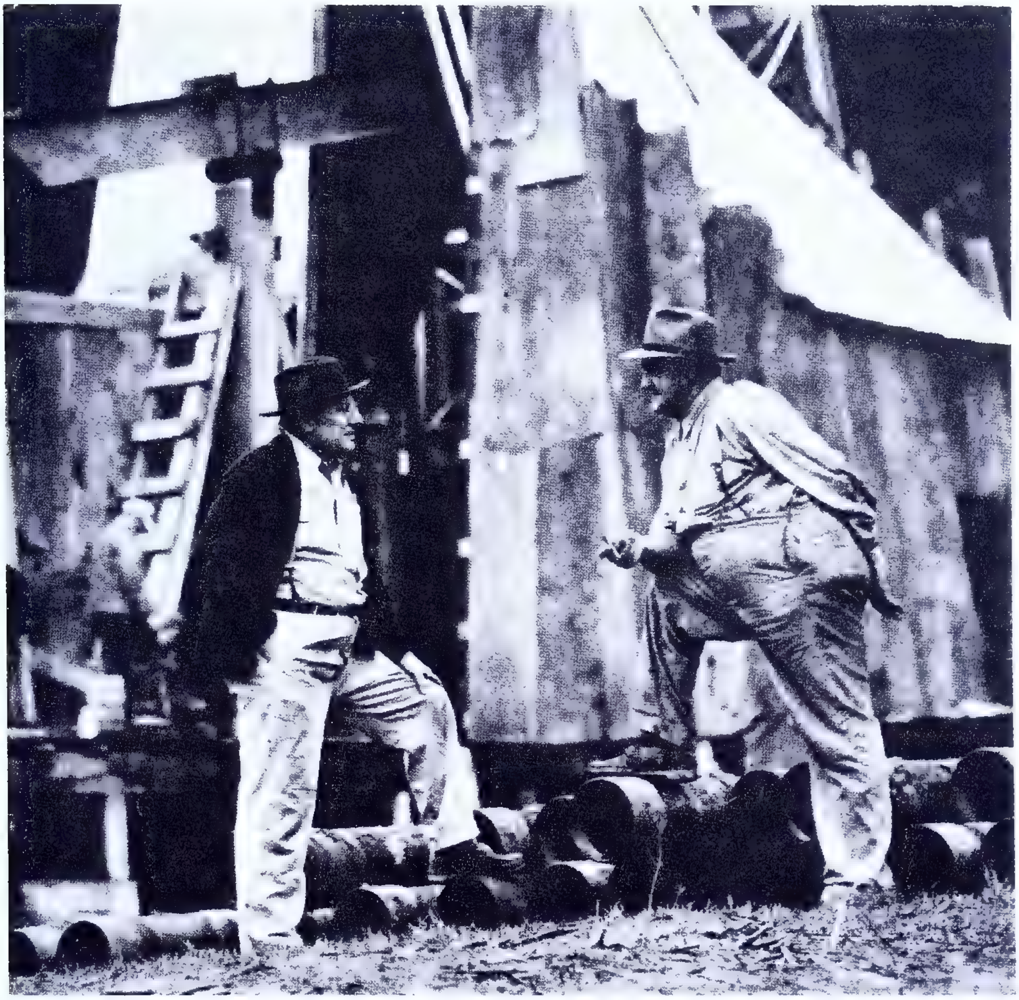

Figure 2. Photograph of Dorcie Calhoun (right) talking with drilling contractor Sam Jack beside a cable-tool rig used to drill to the Ridgeley Sandstone in the Leidy field (photograph reproduced from Philadelphia Inquirer Magazine, November 12, 1950).

that the trucks would not move, Dorcie simply decided to drill on the spot (Figure 3).

The old cable-tool rig spent more time in repair than it did in drilling. The framework had to be rewelded, wooden pieces were replaced by iron or steel ones, sections had to be brought in from outside the area, and additional guy wires were attached to keep the old derrick from falling over. Most of the knowledgeable people who saw it were amazed that it stayed upright and could still be used.

Suddenly, on Sunday afternoon, January 8, 1950, the drillers heard a rumble deep in the ground and began hauling the tools out of the hole as fast as they could. The drilling cable, however, flew out of the hole faster than the bull wheel could reel it in. Realizing the meaning of this phenomenon, the experienced rig hands scattered and took cover. The cable had broken, leaving the drill bit stuck in the hole, but the gas coming up the well bore was under enough pressure to squeeze past the obstruction and still fling the cable out of the

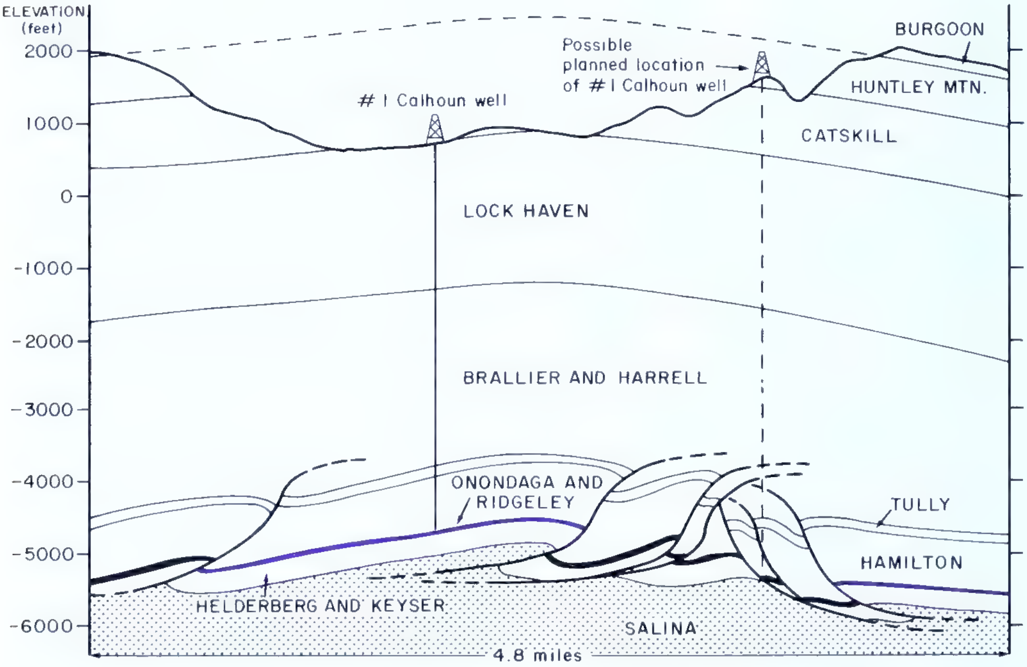

Figure 3. Cross section of a portion of the Leidy field showing the location of Dorcie Calhoun's well, and a possible location of the well as originally planned, in relation to the geologic structure. Notice that the surface and subsurface axes of the Wellsboro anticline are offset, and that the "crest" of the anticline at the depth of the Ridgeley is a graben structure related to salt movement in the Salina Group. Ridgeley gas reservoirs (in color) are restricted to fault-bounded flexures on the flanks of the anticline.

well, where it almost demolished the rig. The well had reached total depth in the Ridgeley at 5,659 feet, and the gas rushing out of the well was estimated at 15 million cubic feet of gas per day, an incredible volume even by today's standards. Dorcie Calhoun and his corporation of farmers and small businessmen had struck it rich and, in the ensuing excitement over this important discovery, ushered in a new era of drilling for oil and gas in the Appalachian basin.

The structure of the Leidy field is illustrated in Figure 3. At the surface the structure consists of a simple asymmetrical anticline, but deep in the subsurface it consists of a central graben (the "crest" of the anticline) flanked by a series of overthrusted limbs; the axis of the anticline is offset to the southeast relative to the surface axis. This effect was created by movement within the ductile layers of salt in the Upper Silurian Salina Group, and probably resulted from a redistribution of salt from the area of the graben to the overthrusted flanks. The exact number and distribution of faults is not known for certain, but they created a set of independent flexures situated on the flanks. The areas of structural closure on these flexures correspond to the gas-producing pools of the Leidy field.

The importance of serendipity in the discovery of oil and natural gas is almost always understated. In fact, without it the Leidy field might still be undiscovered today. New York State Natural Gas was ready to stake a well near Leidy when Dorcie Calhoun began drilling "on a wing and a prayer," and the company decided to hold back, waiting to see what would happen. If it had not been raining that day, Dorcie Calhoun's lead truck would have reached the top of the mountain (possible location shown in Figure 3). The well probably would have been a dry hole drilled into the graben at the "crest" of the subsurface anticline. At that point Leidy Prospecting Company would have failed, New York State Natural Gas would have seen Leidy as a slim prospect for future exploitation, and the drilling "boom" of the 1950's may have been delayed or may never have occurred.

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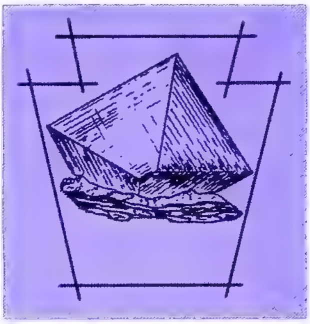

EARTH SCIENCE TEACHERS' CORNER

by James R. Shaulis

Pennsylvania Surfaces in Two New Maps

Those who have been curious about the character, makeup, and origin of the unconsolidated deposits located at or near the surface of Pennsylvania, or who have been wondering how the Piedmont physiographic province differs topographically, compositionally, and structurally from the Ridge and Valley physiographic province need look no further than two maps recently published by the Pennsylvania Geological Survey.

Map 64, **Surficial Materials of Pennsylvania**, colorfully shows the geographic distribution of 12 categories of surficial deposits found across the state. On the reverse side of the map are explanations of the categories, which include stratified sand and gravel, stream terrace deposits, glacial diamicts, residuum, colluvium, and alluvium. The explanation provides general information on areal distribution, thickness, and lithology. Some commonly used surficial geologic terms are also defined. The map will provide both teachers and students of earth science with a general introduction to the surficial geology of Pennsylvania.

Map 13, **Physiographic Provinces of Pennsylvania**, is a significant revision of an earlier version that was compiled over 25 years ago. Boundaries for the physiographic provinces have been revised and, consequently, the names identifying the provinces and sections have been changed in several areas, such as in the plateau region of western Pennsylvania. In addition, a table of descriptive elements (e.g., dominant topographic form, underlying rock type, geologic structure, and drainage patterns) has been printed on the reverse side of the map. This information will help the earth science student to understand the reasons for the geographic distribution of the physiographic provinces in Pennsylvania.

Both maps have been published in a convenient 8½- by 11-inch format, making them well suited as a classroom handout or a notebook supplement. These maps have been printed in bulk quantity and will be provided free to earth science educators, students, and others who wish to know more about the physiography and surficial geology of the Commonwealth. To order copies of Maps 13 and 64, please write to Pennsylvania Geological Survey, P. O. Box 2357, Harrisburg, PA 17105.

Freshwater Limestones of the Allegheny Group

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INTRODUCTION. Freshwater limestones commonly occur in thin beds below the coals of the upper Allegheny Group of western Pennsylvania (Figure 1). They are easy to pick out in roadcuts or surface-mine highwalls as the knobby, pale-yellow beds about 3 feet below the coal; commonly an underclay occurs between the coal and the limestone. The limestone appears, in places, to be a layer of coalesced nodules having an undulose base and top. Upon close inspection, some of those "nodules" reveal a brecciated texture. Although some of the clasts in this breccia show bedding, internally laminated limestone strata are very rare in outcrop, making an interpretation difficult. In other words, the primary beds that were brecciated are hard to find. Clearly, these rocks have had a complicated history. To compound the enigma of their origin, the freshwater limestones in Pennsylvania are commonly associated with another unusual and poorly understood group of rocks, the flint clays (Bragonier, 1989). The lack of modern analogues, as well as rarity of good exposures in Pennsylvania, has plagued attempts to interpret both rock types.

The earliest occurrence of freshwater limestones in the Appalachian basin is in the Middle Pennsylvanian below the Upper Kittanning coal. Above that horizon, freshwater limestones are a common constituent of the coal cyclothems, both in the relatively nonproductive Conemaugh Group and in the productive coal measures of the upper Allegheny and Monongahela Groups (see Figure 1). Just what "event," or change in the basin dynamics, is the underlying cause of this sedimentologic response remains a controversial topic. To date, very little work has been done on these unusual rocks (Adams, 1954; Williams and others, 1968; Marrs, 1981; Cecil and others, 1985; Weedman, 1988).

The purpose of this paper is to describe the results of a study of the Upper Freeport limestone from the subsurface in Indiana and Armstrong Counties (Figure 2), where the limestone reaches thicknesses as great as 30 feet. Fresh core samples through thick sequences have provided a greater variety of calcareous microfacies, including primary bedding, than have ever been described in outcrop.

GEOLOGIC SETTING. The upper Allegheny Group of western Pennsylvania was deposited in late Middle Pennsylvanian time on an upper delta/alluvial plain of the eastern North American foreland basin.

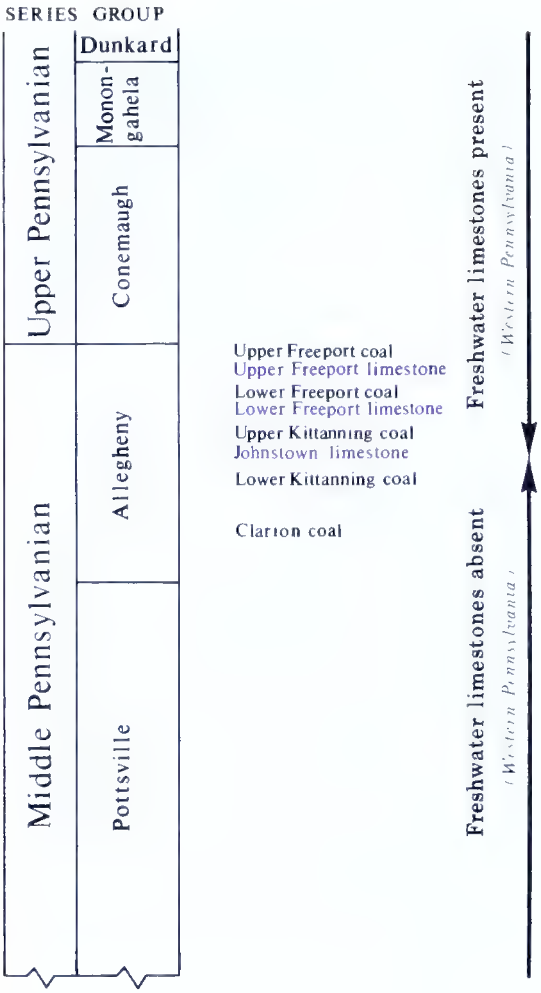

Figure 1. Stratigraphic column of part of the Pennsylvanian System in western Pennsylvania. The major commercial coals and associated freshwater limestones are shown for the Allegheny Group. The distribution of freshwater-limestone-bearing coal cycles is shown by the large vertical arrows.

Sediments infilling the basin were derived primarily from the mountains rising to the south (the Alleghanian orogeny) and are considered to be synorogenic. The upper Allegheny Group limestones—the Johnstown, Lower Freeport, and Upper Freeport—are virtually indistinguishable in the field or in core, and so are assumed to have a similar origin. They appear to have been deposited in broad, shallow alkaline lakes that were subsequently filled in with sediment and peat (which later became the coal). Unfortunately, less is known about the Conemaugh freshwater limestones.

The study was organized around two questions: (1) how do the freshwater limestones fit into the coal-to-coal depositional cycle; and (2) what environmental processes control the unusual appearance of the limestone itself? The first question was answered by a statistical study of vertical lithofacies sequences, as seen in over 450 cores through the upper Allegheny Group, and the second question was answered by an examination of 37 cores of limestone through the same interval.

FRESHWATER LIMESTONES AND THE COAL CYCLE. Based on a statistical analysis of lithofacies sequences (a Markov chain analysis), as seen in cores through the upper Allegheny Group in Indiana and Armstrong Counties, the following preferred sequence was identified: coal → black shale → dark gray to black sandy shale → sandstone → gray sandy shale → silty claystone → claystone → limestone → clay-

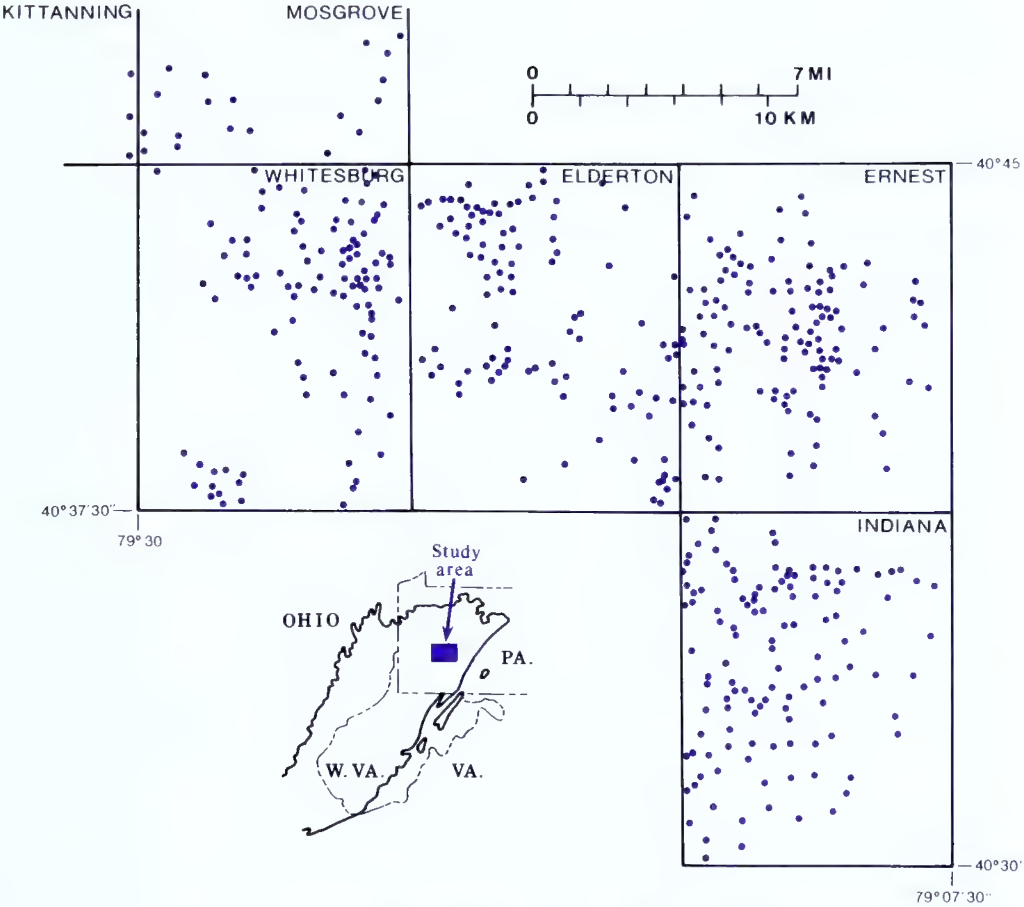

Figure 2. Map of the six-quadrangle study area in western Pennsylvania showing locations of core holes. Core logs from these holes were examined for the interval of the upper Allegheny Group. The inset map shows the location of the study area within the Appalachian basin (bold outline).

stone (underclay) → coal (Figure 3) (Weedman, 1988). This type of analysis provides a convenient way to summarize what is, in fact, a very complex data set. A great deal of variation in vertical lithofacies sequences exists in these sediments; the cycle listed above is only the most frequently occurring and is by no means complete at each site. The method is described in Walker (1984). This cycle looks very much like the classic cyclothem, but it suggests much more variation in lithofacies sequences; note the two-way arrows in Figure 3.

Fossil evidence suggests that the entire interval from the Upper Kittanning coal to the Upper Freeport coal in the study area is nonmarine. The first part of the cycle, from the coal to the sandstone, is a coarsening-upward sequence and is interpreted as the progradational deposits of overbank flows and crevasse splays. The other half of the cycle, from the sandstone to the claystone, is a fining-upward sequence

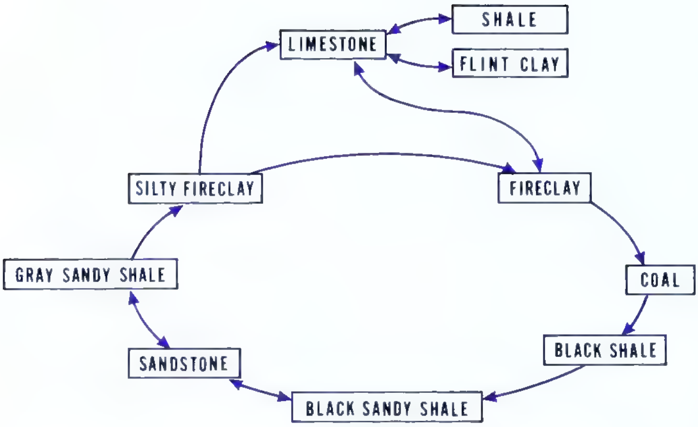

Figure 3. A general lithofacies sequence diagram for the significant lithofacies transitions in the coal-to-coal intervals that contain the Upper Freeport limestone in the upper Allegheny Group in western Pennsylvania. A single arrow (→) means "is overlain by," and a double arrow (↔) means "is interbedded with."

and is interpreted as the deposits that accumulated on the floodplain after the abandonment of the main channel. In other words, detrital deposition was replaced by chemical and organic deposition. Isopach maps of both the sandstone and limestone of the same coal-to-coal interval show that the thickest limestones occur over the thinnest sandstones, and the thinnest limestones occur over the thickest sandstones. Assuming that the thickest sandstones represent channels and the thickest limestones were deposited in the deepest parts of the lakes, this offset relationship suggests that the lakes were floodplain lakes, as opposed to abandoned channel meanders (i.e., oxbow lakes). The lake location was determined, then, by the location of the river or distributary channels, or their levees.

The following depositional scenario is envisioned for the "complete" cycle:

(1) The peat swamp (*coal*) is flooded with sediment-laden water from a nearby newly avulsed channel. The introduction of muddy sediment into the peat swamp produces a fissile dark-gray to black shale (*black shale*).

(2) As progradation of overbank sedimentation continues, organic-rich clays, silt, and sand continue to cover the peat swamp from distal overbank flows (*black sandy shale*).

(3) Sand is deposited over the dark sandy mud as more proximal overbank or crevasse flows reach the distal areas of the floodplain; progradation is at a maximum (*sandstone*).

(4) The deposition of light sandy mud suggests that the progradation of crevasse splays is waning. The lighter color can be interpreted as either a decline in vegetation or an increase in subaerial exposure (*gray sandy shale*).

(5) The appearance of a massive silty mud over the sandy mud signifies that the source of coarse sediment has avulsed upstream, and the newly deposited muds have been bioturbated or rooted to oblit-

erate bedding. However, the abandoned channel should still contain water, which transports sediment in suspension, and, during flood, transports the suspended sediment to floodplain lakes; the old channel and levee will be gradually buried in flood sediment (*silty fireclay*).

(6) Levee buildup and progradation during active sediment transport in the channel leads to the formation of topographic highs over the sites of sand deposition. Continued subsidence, combined with a marked decline in sedimentation rates after avulsion, results in perennial flooding of the floodplain. Freshwater lakes form in the low areas, are colonized by cyanobacteria, and are infilled with biogenic carbonate, floodborne mud, and vegetation. Lateral and vertical variation of the various lacustrine facies is controlled by water depth and proximity to both shoreline and sediment source (*limestone, shale, flint clay, fireclay*).

(7) A peat swamp migrates over the lake from the margins as it fills in with sediment and vegetation; the cycle is complete (*coal*).

The cycle can be interrupted at any point by the deposition of a channel or crevasse splay, or a distal equivalent. A block diagram is shown in Figure 4, representing a time just after avulsion but before the maximum expansion of the lake.

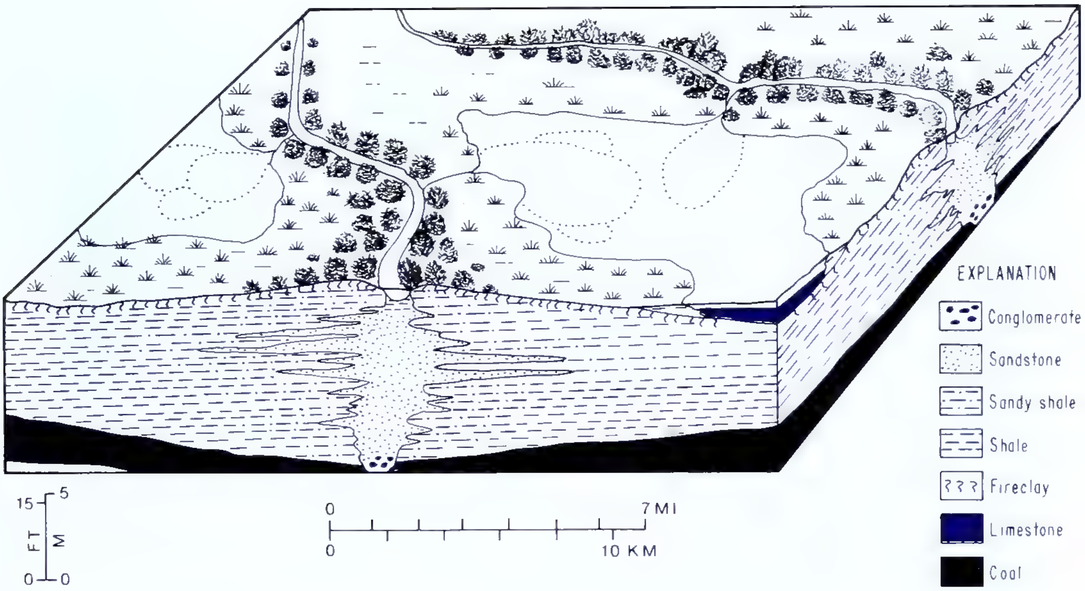

Figure 4. The depositional model for the Upper Freeport limestone and associated lithofacies. The paleogeography depicted in the model represents a time just after the upstream avulsion of the channel but before the maximum lake expansion and peat swamp formation. The form of muddy lacustrine deltas is indicated by the dotted lines in the lake areas. Though the channels are abandoned, they can transport suspended load to the floodplain and lake during flood.

THE LIMESTONE. The abundance of micro-oncolites and "algal" bedding in the limestone suggests that the lakes were colonized by cyanobacteria (Figure 5). Additional fossils include numerous kinds of ostracodes (not yet studied), *Spirorbis* worm tubes, fish bones, freshwater shark teeth, and plants. In eastern Ohio, the cannel coal at the famous Linton deposit, which overlies the Upper Freeport limestone, has yielded an abundance of vertebrate fossils of reptiles, amphibians, fish, and freshwater sharks (Hook, 1985). These fossil remains suggest that an abundance of animal life inhabited the Middle Pennsylvanian lakes and bogs.

The Upper Freeport limestone, from examination in cores, can be divided into seven calcareous microfacies: an encrusted grain microfacies (the micro-oncolites), a massive micrite, a laminated micrite, a clastic limestone, a claystone-limestone disturbed microfacies, a matrix-supported breccia, and a calcareous claystone. Calcite, dolomite, siderite, and ankerite are the only carbonate minerals; no true evaporite minerals have been reported. The calcareous microfacies are interbedded with three detrital lithofacies: claystone, black shale, and gray silty shale.

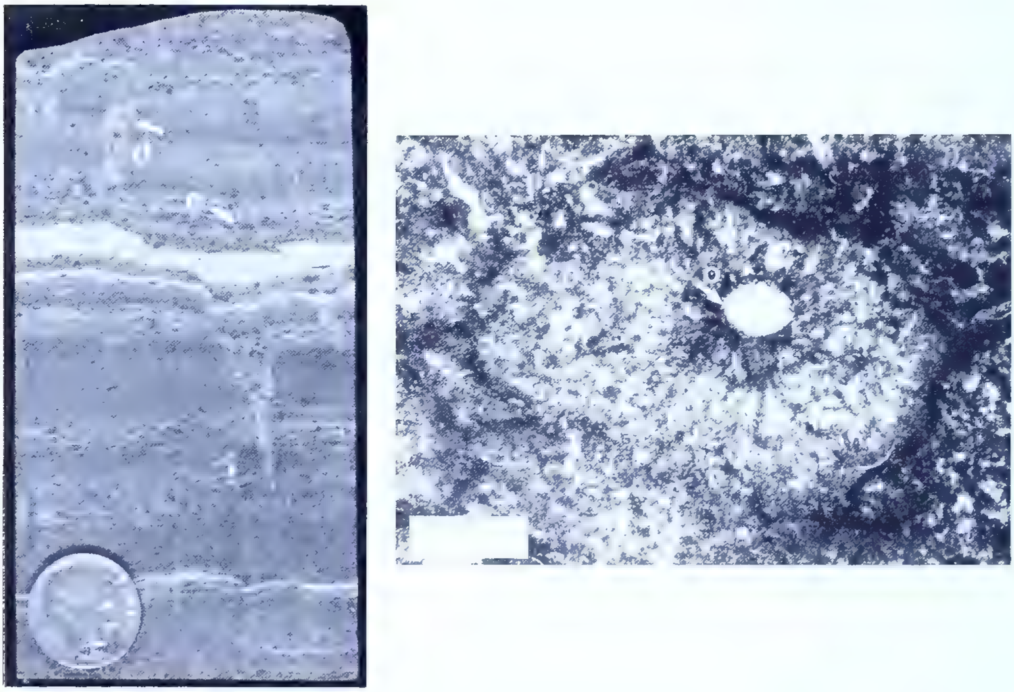

Figure 5. The encrusted grain microfacies (micro-oncolites). A. The core half shows dark-gray encrusted grains (e) in a lighter gray micrite matrix. Clay dikes (d) are filled with darker clasts of wall rock in a lighter clay-rich matrix. B. Photomicrograph of a single ostracode (o) encrusted by radiating cyanobacterial filaments that have been enhanced by etching in 0.1 percent hydrochloric acid. Scale bar is 0.5 mm in length.

In general, the thinnest limestone deposits (3 to 7 feet thick) are dominated by either a matrix-supported breccia or a clastic limestone, and are interpreted as shoreline facies. The thicker limestones (10 to 17 feet) comprise a variety of all of the microfacies, and show well-preserved bedding. The matrix-supported breccia and clastic limestone are absent in the thickest limestone deposit examined (17 feet). The limestones are characterized by abundant dewatering structures that show the injection of shale or claystone into the overlying, early cemented limestone. In plan view, these structures resemble desiccation cracks. The hypothesis is that compactible beds (shales, claystones, etc.) were episodically injected into the relatively early cemented and less permeable calcareous beds when the pore pressures in the shales exceeded the confining pressures of the limestones.

CLIMATE VERSUS BASIN DYNAMICS (OR, WHY ARE THE LIMESTONES WHERE THEY ARE?). Two hypotheses have been proposed for the sudden appearance of lacustrine limestones in the Pennsylvanian. First, their occurrence has been attributed to a change from a relatively wetter to a relatively drier climate during Middle Pennsylvanian time (Cecil and others, 1985; Donaldson and others, 1985). This interpretation is supported by assumed climatically controlled changes in the composition of the coals and sediments that are interbedded with the limestones. The underlying assumption is that, as evaporation increased relative to precipitation, surface waters became more enriched in calcium, and calcite precipitation occurred. Studies of modern lakes, however, have shown that calcite can precipitate in lakes in wet climates if there are limestones exposed in the source area and cyanobacteria available to mediate the precipitation. If the only change in the depositional environment were an increase in dryness, then one would expect all lithofacies of the coal cycle to be slightly calcareous. The general observation, however, is that limestones occur in discrete beds below the coal; small traces of calcite have been reported in the coal itself.

An alternative view is that lacustrine deposition was made possible by a changing fluvial style that favored the formation of lake basins in abandoned areas of the floodplains. That changing fluvial style, from meandering to anastomosed, is attributed to a response to an increase in subsidence rates relative to sedimentation rates, or, in other words, the inability of the surface drainage system to fill in the basin fast enough to keep up with subsidence (Weedman, 1988). The subsidence argument holds that the predominance of subsidence over sedimentation led to the formation of prominent levees along river channels (vertical accretion), to shoestring-shaped sand bodies (unfortunately, only indirect evidence exists for sand-body shape), and to frequent avulsions. With each avulsion, some area on the floodplain would be left abandoned by the sediment-dispersing channel and would not receive adequate detrital sedimentation to fill in the lows. Those irregularly surfaced, abandoned areas would be ideal locations for calcareous algal (cyanobacterial) marshes and lakes (see Smith and Putnam, 1980, for a discussion of anastomosed river systems).

In summary, one hypothesis is based on the need for an adequate calcium supply in lake water to favor the precipitation of calcite, and the other is based on the need for a cyclic mechanism for the formation of sediment-starved lakes. One hypothesis, of course, does not preclude the other. Further work on the ways in which the depositional environments of the different freshwater limestones in the Appalachian basin changed through time may help to put these two hypotheses in better perspective.

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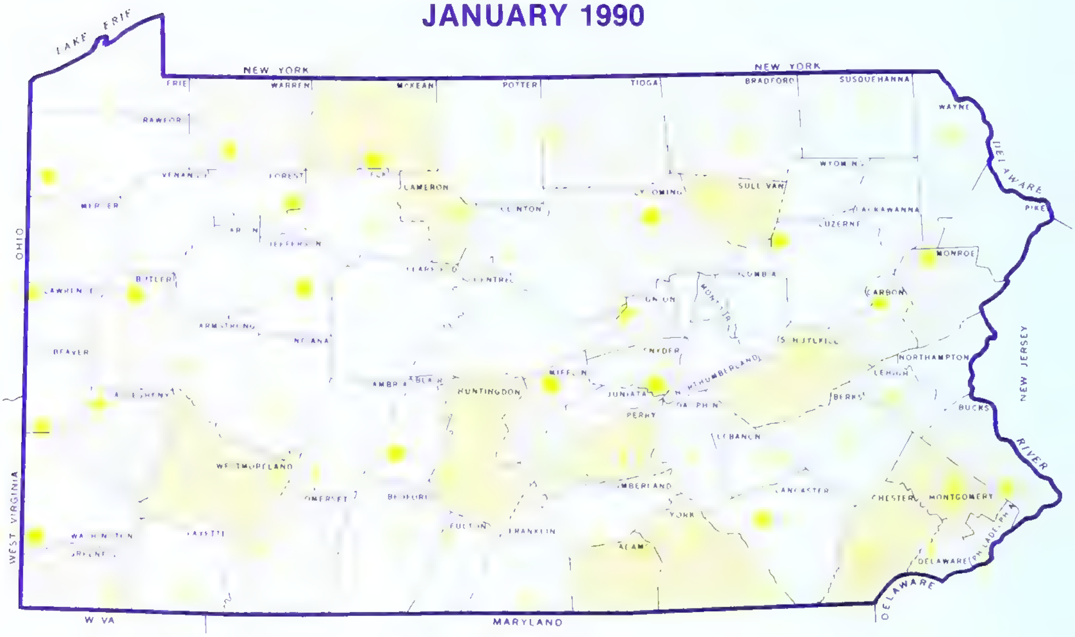

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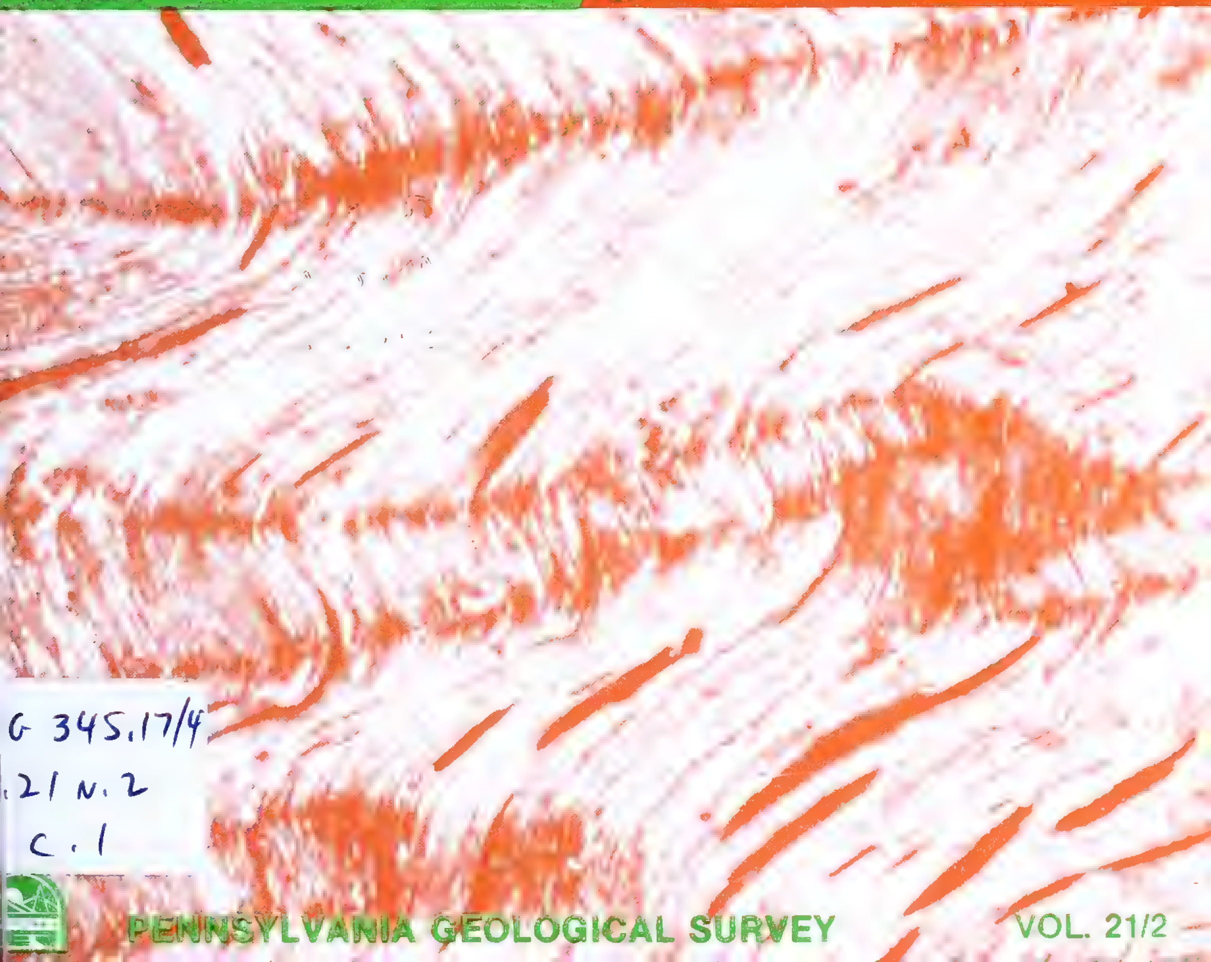

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PENNSYLVANIA GEOLOGICAL SURVEY

VOL. 21/2

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ON THE COVER: Crenulations (microfolds) in the Marburg Schist of York County as viewed under a microscope (cross-polarized light). The axial planes of the crenulations are parallel to the second regional (S2) schistosity, which is discussed in relationship to schist of the Wissahickon Formation in the article on pages 3-9. The dark bands are coincident with the axial planes. This photomicrograph has been rotated 90 degrees clockwise from the true orientation, making the right edge of the photograph the true top. The horizontal field of view is 4 mm. Photograph by David W. Valentino.

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MAY 29 1990

Earth Day Certainties

Earth Day, 1990, commemorates the first Earth Day on April 22, 1970. New goals focus on building a safe, just, and sustainable planet; the "sustainable common future" of the World Commission on Environment and Development (the Brundtland report). The authors of this report also recognize the need for use of the earth's resources, including its mineral and energy resources.

Geologists are well suited to participate in the decisions of the decades ahead regarding a "sustainable common future," and participate we must. Our perspective of geologic time and earth events allows us to state some certainties of which all must be aware:

1. The earth is not fragile as some would believe—it is only life that is fragile. The earth existed for many millions of years without any atmosphere and hydrosphere; only the lithosphere was there. The lithosphere will persist without air and water.
2. The dynamism of our celestial system and cycles within the earth will produce natural change far greater than any man-induced change. That these natural changes may produce catastrophes far greater than any previously experienced by man does not make them any less natural.
3. Even knowing these certainties, geologists and other scientists also know that there are immense uncertainties associated with understanding the interrelationships of the lithosphere, hydrosphere, and atmosphere. Predicting the behavior of the systems is not yet possible.
4. The oft-stated aphorism "If it doesn't grow it must be mined" is true now and will be in the future. Although resource recovery disrupts the earth's surface, it can and is being done in an environmentally benign manner. Stating this does not imply that unrestrained growth is possible or desirable, only that maintenance of current human-engineered structures requires mineral resources.

A certainty of the 1990 Earth Day, as it is of every day of our earth, was stated by Van Loon in his 1932 book *Geography*: "We are all of us fellow passengers on the same planet and we are all of us equally responsible for the happiness and well-being of the world in which we happen to live."

Donald M. Hoskins

Donald M. Hoskins
State Geologist

IN MEMORIAM

Harry F. Ferguson (1921–1989)

Harry F. Ferguson passed away on November 4, 1989, after a long illness. He was an outstanding practitioner in the field of engineering geology, a professional who consistently emphasized the fundamentals in developing a geologic framework and relating it to the engineering requirements of the project. Through his many contributions, both with the U.S. Army Corps of Engineers and in private practice, he had a major influence on the practice of engineering geology in the upper Ohio River basin.

When Harry graduated from the University of Pittsburgh in 1949 with a B.S. degree in Geology, he joined the Groundwater Branch of the U.S. Geological Survey in Baltimore and conducted groundwater investigations throughout Maryland. In 1955 he transferred to the Military Geology Branch in Washington, D. C., where he was part of a team that developed terrain intelligence reports on strategic foreign areas.

Harry's career shifted to engineering geology in 1956 when he returned to Pittsburgh to work at the Pittsburgh District office of the U.S. Army Corps of Engineers. For the next decade he worked closely with District Geologist Shailer Philbrick, handling all geological and geotechnical aspects for the subsurface investigation, design, and construction of numerous flood-control dams, navigation locks, and flood-protection projects. Geological observations made by Harry during the excavation of numerous rock foundations for civil engineering projects throughout the Allegheny Plateau led to his pioneering work on valley stress relief, published in 1967. Harry succeeded Dr. Philbrick as District Geologist in 1966, and was named Chief of the Foundations and Materials Branch (later Geotechnical Branch) of the Pittsburgh District in 1972, one of the first two geologists to serve in that capacity. Following his retirement from the Corps in 1980, Harry practiced full time as a geotechnical consultant on a wide range of projects until the time of his death.

Harry was also a great influence for many young geologists and colleagues through his discussions at technical meetings and on field trips. He was an active participant in many professional and community organizations, and served as chairman of the Engineering Geology Division of the Geological Society of America in 1982.

Harry will be deeply missed by his many friends and colleagues within the geologic community. He is survived by his wife Vivian, his son Michael, and three daughters, Sandra, Jill, and Andrea.

by Richard E. Gray

A Linear Segment of the Martic Line: an Example of Dextral Transposition in the Piedmont Province of Pennsylvania

by David W. Valentino
Pennsylvania Geological Survey

Introduction

After an absence of nearly two and a half decades, the Pennsylvania Geological Survey has returned to the Piedmont province! This most complex of Pennsylvania's geologic terrains was the focus of much government-funded research in the first half of this century. Through the efforts of Florence Bascom, Eleanora Bliss Knopf, Anna Jonas, and George Stose, nearly all of the Piedmont was geologically mapped at a scale of 1:62,500. The new paradigm of plate tectonics and a quantum leap in our understanding of structural and metamorphic processes make revision of this old mapping necessary. Although the early workers recognized metamorphic minerals and rock structures, these geologic elements were not interpreted in the context of multiple orogeny, lithotectonic units, and crystal plastic flow. To remedy this situation, the Pennsylvania Survey has focused a major new mapping initiative in the Piedmont, the first phase of which is a detailed study of the metamorphic rocks exposed on the east side of the Susquehanna River gorge between Columbia, Lancaster County, and the Maryland line (Figure 1). This recent reconnaissance work has resulted in some exciting and thought-provoking findings (Faill and Valentino, 1989; Valentino, 1989).

Recognition and interpretation of microstructures in schist of the Wissahickon Formation exposed in the lower Susquehanna gorge provide evidence for horizontal compression and strike-parallel ductile faulting, which were not previously recognized. The "fault zone," or ductile shear zone, incorporates part of the enigmatic Martic Line, the contact between the Cambro-Ordovician Conestoga Formation and the Precambrian-Lower Paleozoic(?) Wissahickon Formation. Wissahickon phyllonite in the Turkey Hill area south of the Martic Line (Figure 2) contains subvertical crenulations and cubic pyrite crystals (5 to10 mm across) with attached quartz pressure fringes. Crenulations are the result of horizontal compression, and asymmetric dis-

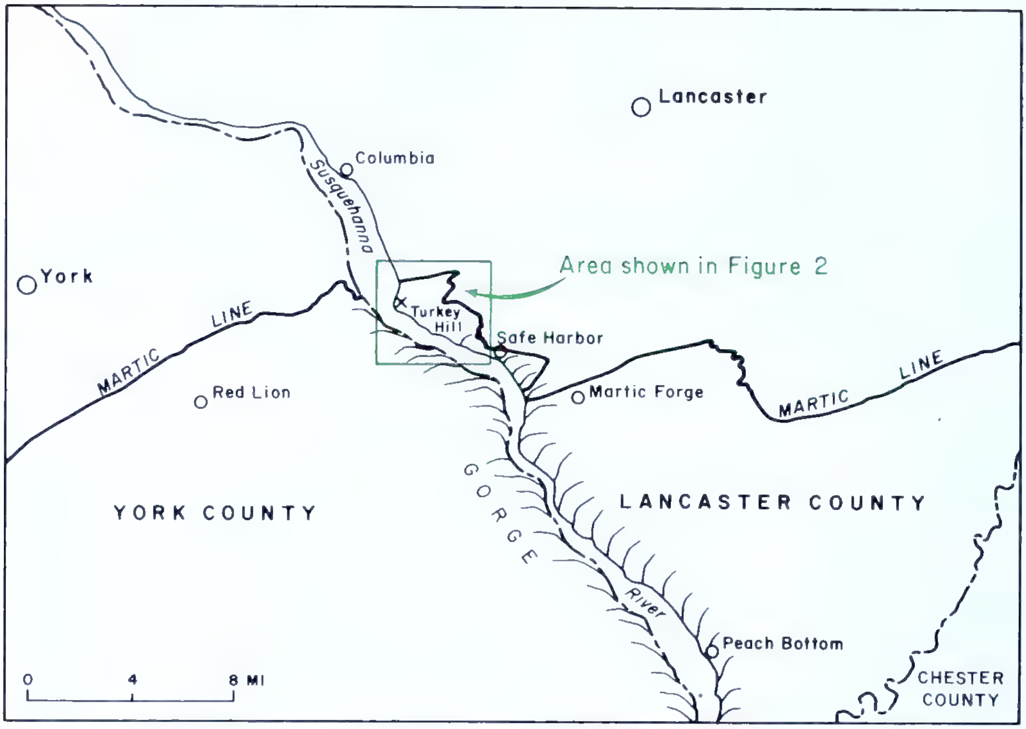

Figure 1. Map of Lancaster and York Counties showing the Susquehanna River gorge.

tribution of the quartz pressure fringes indicates dextral (right-lateral) ductile shearing.

Schistosity Relationships

The Wissahickon schists and phyllites bear interesting schistosity relationships in the area between Safe Harbor and Turkey Hill. At Safe Harbor, schistosity in Wissahickon schist is defined by parallel alignment of coarse chlorite, muscovite, biotite, and planar aggregates of plagioclase feldspar and quartz (S1). This S1 schistosity strikes 245° to 260° and dips moderately 40° to 50°NW. North of Safe Harbor, the S1 schistosity gradually steepens. As Turkey Hill is approached from the south, the schistosity (S1) progressively shows signs of weak to intense upright crenulation (small-scale folding having wavelengths up to a few millimeters). At Turkey Hill, crenulation of the S1 schistosity (Figure 3) was so intense that a new subvertical schistosity (S2) striking 070° developed and practically obliterated the S1 schistosity (Figure 4). This new (S2) schistosity is now defined by parallel alignment of very fine (submillimeter) musco-

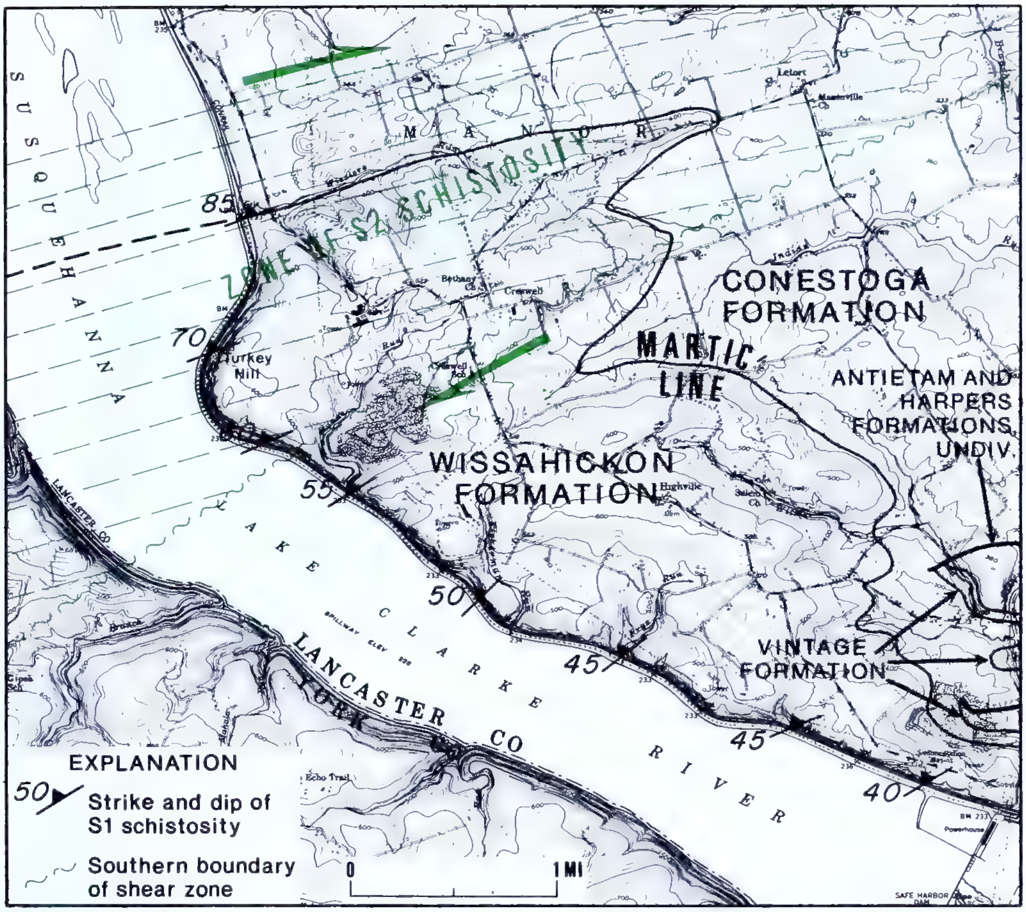

Figure 2. Bedrock and structure map of the Turkey Hill area, Lancaster County, Pennsylvania. The northern boundary of the zone of S2 schistosity is beyond the upper limit of this map.

vite and chlorite crystals and recrystallized planar quartz aggregates. Diamond-shaped profiles of intersection lineations (S2 x S1) clearly show the relative timing between the two schistosities.

Pyrite Crystals with Quartz Pressure Fringes

Oriented rock samples cut from the schist at Turkey Hill show pyrite crystals that have asymmetric quartz pressure fringes. The profiles of these microstructures are best observed on surfaces cut perpendicular to new (S2) schistosity and roughly parallel to the earth surface (horizontal). Pyrite crystals range in size from 5 to 10 mm, and the quartz pressure fringes are commonly twice the length of the host pyrite crystal (Figure 5).

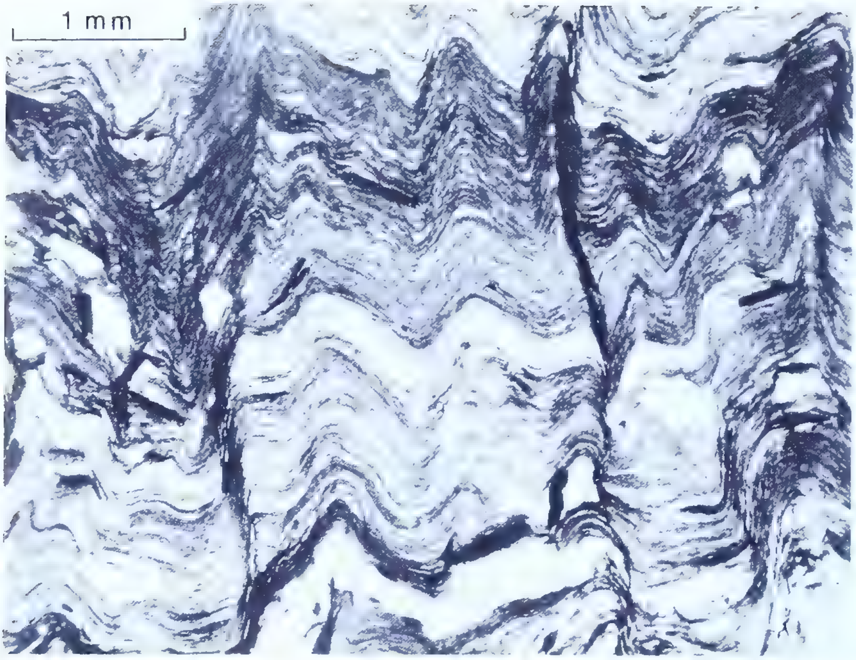

Figure 3. Photomicrograph of crenulations and weak second (S2) schistosity developed on the first (S1) schistosity. The view is looking 260 degrees at a nearly vertical surface.

How do these structures develop? At the onset of ductile shearing the rock begins to flow, allowing for growth of quartz in the direction of maximum extension (Ramsay, 1967) adjacent to the rigid pyrite crystal (Figure 6A). Continued shearing is accompanied by further quartz growth (Figure 6B). The final result is a pyrite crystal that has quartz pressure fringes distributed asymmetrically about the crystal;

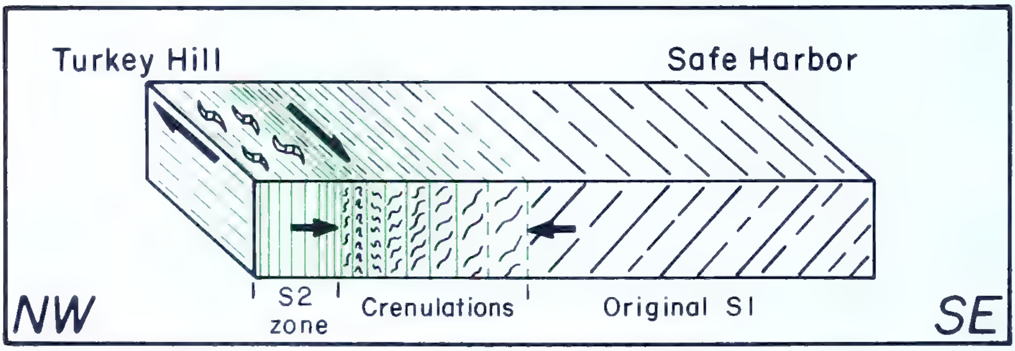

Figure 4. Schematic block diagram showing the development of the second (S2) schistosity; the first (S1) schistosity is shown as a reference structure.

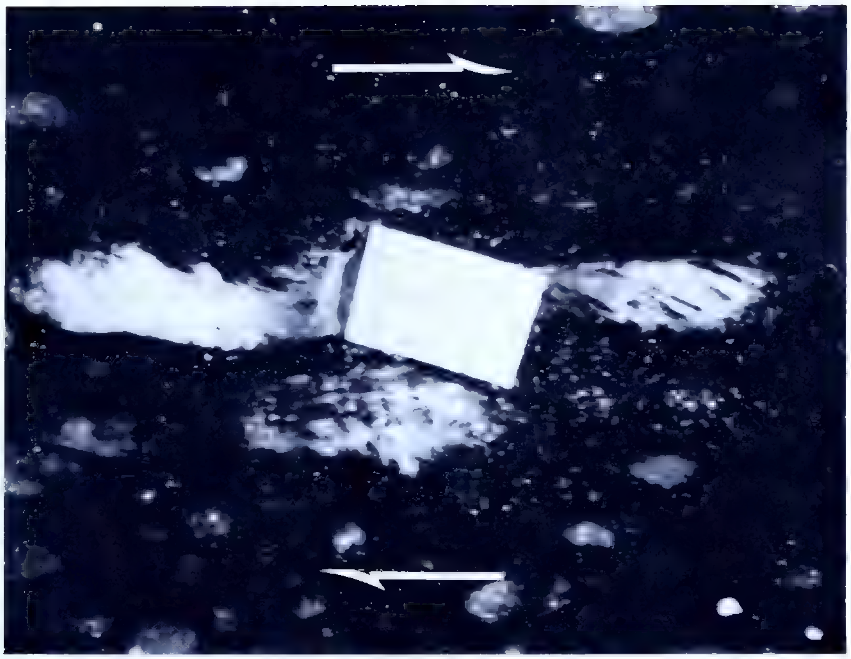

Figure 5. Pyrite crystal (6 mm across) having quartz pressure fringes associated with the second (S2) schistosity.

the pressure fringes point in the direction of structural offset (Figure 6C). The implications of asymmetric distribution are that (1) the rock has undergone simple shear; and (2) the shear sense can be determined (Ramsay, 1967; Ramsay and Huber, 1983; Simpson and Schmid, 1983; Etchecopar and Malavieille, 1987).

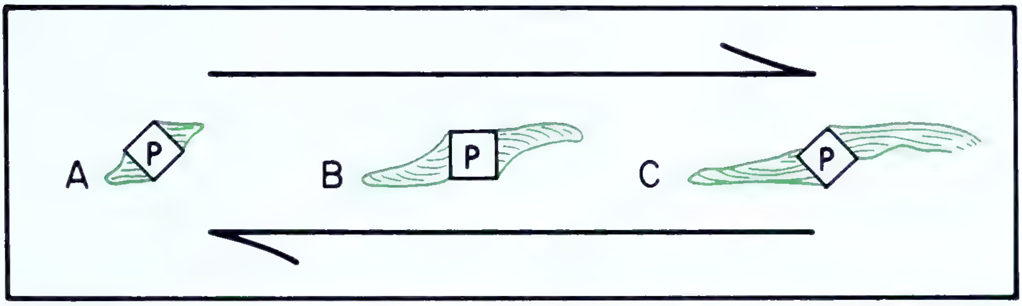

Figure 6. Schematic diagram showing the development of quartz pressure fringes. A. Ductile shear allows for quartz growth in the direction of maximum extension. B. Continuous ductile shear allows for further growth of the pressure fringe. C. The final quartz pressure fringes are distributed asymmetrically about the host pyrite crystal.

Regional Implications

The zone of second (S2) schistosity is located along the northernmost contact of the Wissahickon Formation and the Conestoga (marble) Formation (Figure 2). This formational contact is a linear segment of the Martic Line previously inferred to be a thrust fault (Knopf and Jonas, 1929; Stose and Stose, 1944; Wise, 1970). Although the original juxtaposition of the Wissahickon against the Conestoga Formation may have been by thrusting, the present structure at this contact is not a thrust fault. It is probable that evidence for much earlier structures, if they existed, was obliterated during the development of the first (S1) and second (S2) schistosities.

The crenulations defined by microfolding of the initial (S1) schistosity are associated with the development of the second (S2) schistosity. Crenulations are evidence for rock compression oriented perpendicular to the crenulation axial plane. Because the axial planes of the crenulations are subvertical, the compressive stress was horizontally oriented. The pyrite crystals with quartz pressure fringes that were recognized during this investigation have an asymmetry (upper right and lower left), when viewed looking into the earth, that indicates transcurrent dextral shearing. Microstructural analysis in this second (S2) schistosity zone revealed consistent dextral offset. An unusual linear prong of Wissahickon schist extends eastward into the Conestoga Formation along strike of the second (S2) schistosity zone at Turkey Hill. The overlap of the linear prong of Wissahickon schist with the zone of second (S2) schistosity suggests that the Wissahickon-Conestoga contact (the Martic Line) has been locally transposed dextrally. The combination of crenulations and microscopic shear structures associated with the second (S2) schistosity suggests a model of dextral strike-slip ductile faulting having a strong component of horizontal compression.

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Announcing the

1990 Field Conference of Pennsylvania Geologists

The 55th Annual Field Conference of Pennsylvania Geologists will be held in Lancaster, Pennsylvania, October 4–6, 1990. Special features of the 1990 Conference are as follows:

- The first day will be spent in the Piedmont of southern Lancaster County, where the main topic of discussion will be the metamorphism and structural development of the Tucquan antiform.
- The second day will be spent examining Cambrian limestones between Lancaster and York, with emphasis on problems of correlation in time-transgressive sequences and differences in intensity of deformation.
- Metabasalt, potholes, and landscape evolution are added attractions.

Registration information will be sent in early August. If you are not on the current Field Conference mailing list and wish to attend the 1990 Conference, please write to the Field Conference of Pennsylvania Geologists, P. O. Box 1124, Harrisburg, PA 17108–1124 (*please note new address*).

J. P. Lesley and the Great Anticline Debate

by John A. Harper
Pennsylvania Geological Survey

One of the principal tools used by the petroleum industry in locating potential new oil and natural gas reserves is the so-called "anticlinal theory." This theory was first developed prior to the drilling of Drake's well and was first published in definitive form in 1861. A simplified statement of the theory is as follows: because oil and natural gas are lighter and more buoyant, they will migrate within reservoir rocks to the highest point of an anticline or dome, and water will occupy the lowest points (Figure 1). Therefore, by drilling into the highest point on an anticline, the driller will obtain oil and/or gas rather than water.

Because many anticlines can be mapped at the surface without any knowledge of subsurface geology, especially in areas of gentle structure (Figure 1A), the "theory" worked well in the search for oil and gas in the early years. Therefore, it has been readily accepted by petroleum geologists for over 100 years. But it was not always so well thought of. In fact, from the mid-1860's until well into the 1880's, the anticlinal theory was considered controversial and unsupportable, largely because of the efforts of J. Peter Lesley, Director of the Second Geological Survey of Pennsylvania. Owen (1975, p. 78) claimed that Lesley "probably knew more than any other man about the geology of Pennsylvania" at that time. As chief geologist in the world's leading oil-producing state, Lesley was a force to be reckoned with concerning the geology of petroleum. Although he expressed some early support for the theory in 1863, his opposition to it was firmly set by 1865 and later became something of an obsession.

It is plain why Lesley felt that the theory had no validity in Pennsylvania. His consulting work in the oil fields in the early 1860's taught him that Pennsylvania's oil reservoirs were controlled by stratigraphy rather than by structure. This was later reiterated and clarified by geologists of the Second Survey. The depositional origin of the reser-

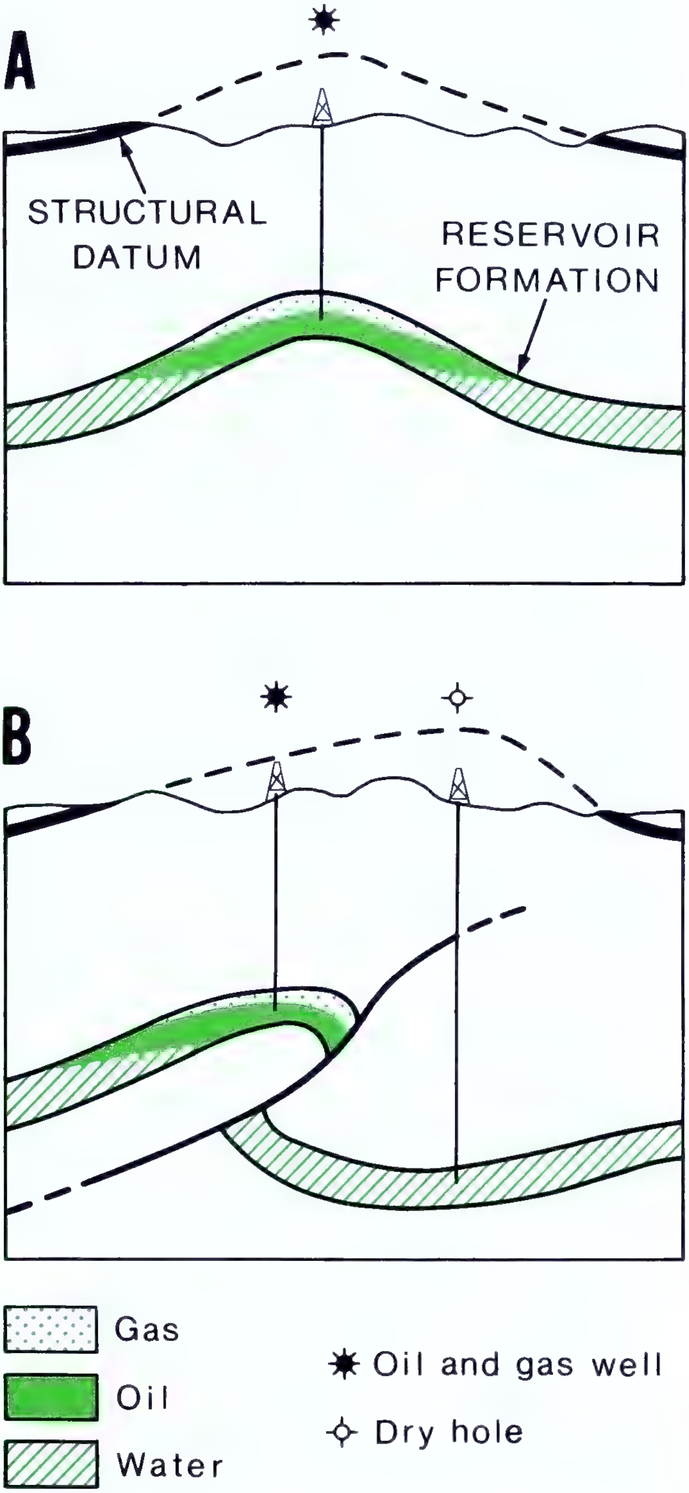

Figure 1. Graphic depictions of the anticlinal theory. According to the theory, oil and gas will be found in the reservoir rocks at the highest point of an anticline. Hydrocarbons can be found easily by using surface structure to delineate subsurface structure in areas of gentle to moderate folding (A). However, in areas where the structure is more intense, surface structure could be misleading, especially when used to the exclusion of all other exploratory methods (B).

voir rock, its geometry, and its composition and grain size were clearly more important to production than structural disturbance. In northwestern Pennsylvania, structure in the oil fields consists almost exclusively of a very low angle regional dip toward the southwest (Figures 2 and 3). In contrast, in central Pennsylvania, where anticlines form an impressive part of the geology, there were no known oil and gas reserves. Still, there is no clear reason why Lesley was so adamant in his opposition to the concept in general, particularly in light of his earlier support. He was so convinced that oil accumulations had nothing to do with geologic structure that he wrote (in Carll, 1880, p. xvi):

> The supposed connection of petroleum with anticlinal and synclinal axes, faults, crevices, cleavage planes, etc. is now a deservedly forgotten superstition. Geologists well acquainted with the oil regions never had the slightest faith in it, and it maintained its standing in the popular fancy only by being fostered by self-assuming experts who were not experienced geologists.

Lesley's convictions were well supported during the work of the Second Survey, mainly by John Carll, the Survey's expert on the oil industry (see, for example, Carll, 1875 and 1880). Carll is often considered by historians, such as Owen (1975) and Galey (1985), to have espoused the anticlinal theory, in direct contradiction to the philosophy of his superior. It this is so, there is no clear indication from his writings to substantiate it, aside from the last sentence of the following quotation (Carll, 1886, p. 73–74):

> . . . the anticlinals and synclinals now seen on the surface should not be taken as guides in searching for the oil-sands. These undulations were produced by movements in the earth-crust long after the oil-sands were deposited—as is shown by the fact that the coal measures are equally affected by the same waves—consequently they could have had no agency whatever in controlling and directing the currents which had already laid down the oil-sands thousands of years before. In so far as these anticlinals and synclinals affect the productiveness of the oil-sands, by affording an opportunity for gas to collect at the crowns of the arches and salt water to settle in the depressions between them, just so far ought they to have an influence in the selection of a location for an oil well, and no farther.

In fact, Carll's published reports indicate that he had very little faith in the idea. Having worked extensively in the oil fields of northwestern Pennsylvania for many years prior to joining the Survey, he, like

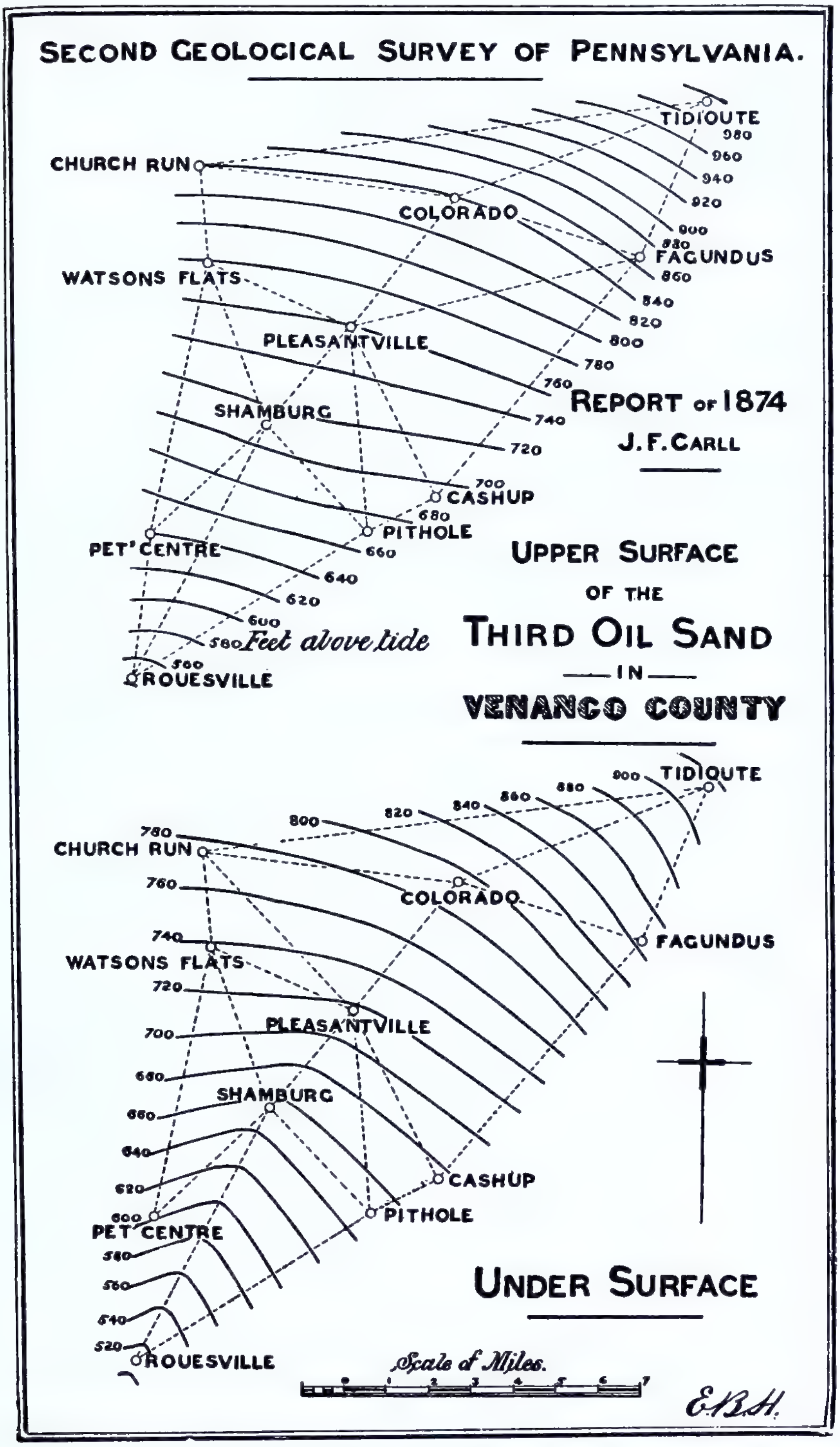

Figure 2. The first published subsurface structure maps, by John F. Carll (1875, p. 19), show that the reservoir rocks in northwestern Pennsylvania dip gently to the southwest.

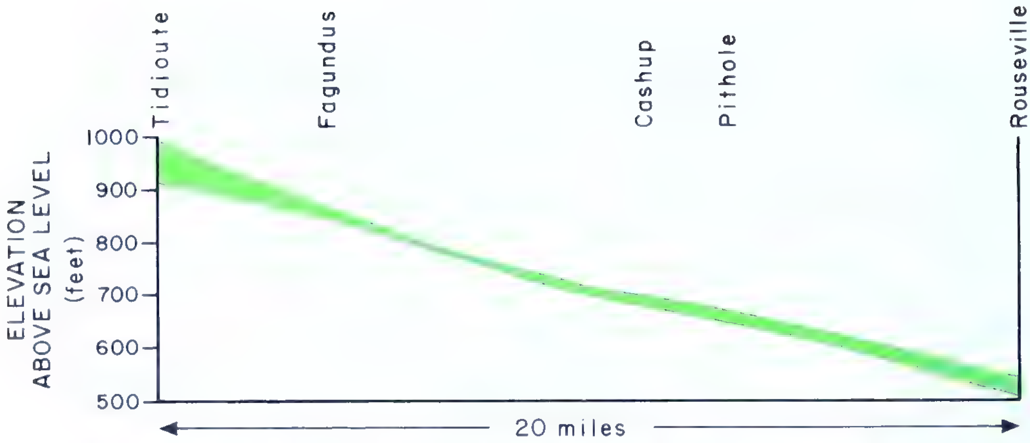

Figure 8. Structural cross section from Tidioute, Warren County, to Rouseville, Venango County, based on Carll's (1875) structure maps of the top and bottom of the Venango Third sand (Figure [illegible]). Variations in sandstone composition and thickness are much more important than structure for controlling reservoir characteristics in this area.

Lesley, was all too aware that the oil pools owed their existence to depositional conditions, not to regional postdepositional disturbances. He stated (Carll, 1886, p. 75) that "the place to look for the guides and indices that will aid us most in an intelligent tracing of the oil-bearing sands is in the rocks themselves, and not . . . in the structure or position of the superimposed strata."

Lesley's determination to repudiate the concept had much influence within the Survey. J. J. Stevenson, the prestigious geology professor who was in charge of the bituminous coal studies of southwestern Pennsylvania, apparently accepted the anticlinal theory but with some reservation. Stevenson lived and worked in West Virginia, and so was very familiar with the successful drilling on the Burning Springs anticline in the northwestern part of that state. But during his tenure with the Second Survey he never expressed a strong opinion of whether or not the theory worked in Pennsylvania. Others, such as H. M. Chance and Charles Ashburner, both of whom had worked in the oil fields of northwestern Pennsylvania, gave only grudging lip service to the theory in reports or letters published outside the Survey. They strongly reiterated Carll's contentions that stratigraphic controls were far more important than structure in governing the emplacement of petroleum.

The one very notable exception to Survey staff indifference or antagonism to the theory was Stevenson's protégé, I. C. White. White was something of a maverick, as adamantly in favor of the concept as Lesley was against it. In fact, White published his own version of the theory in 1885, and actually laid claim to the concept. Most petroleum geologists credit White with giving the theory the impetus and acceptance it deserved, and with bringing the concept into the twentieth century.

Lesley continued to fight the anticlinal theory until his health broke in 1894 (Galey, 1985). Despite his profound influence, however, the concept prevailed. It worked, after all, and to the oil man spending money looking for elusive hydrocarbons, what could be more convincing? In fact, one of the major criticisms by the oil industry at that time was that the Second Survey could only tell them what they already knew, rather than give them a simple and straightforward exploratory tool for finding oil and gas. As stated by DeGolyer (1961, p. 24), "The anticlinal theory had the decided advantage that, in addition to being practically and theoretically as sound as the stratigraphic-trap theory, it afforded useful clues to the prospector in his search for new pools, a value not possessed by the stratigraphic-trap type of pool."

Fortunately for J. P. Lesley, he is remembered well for all of his contributions to geology in general and to the geology of Pennsylvania in particular. It would be a monumental mistake to denigrate a man of such historical and scientific importance simply for the sake of one misjudgment.

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Association of Engineering Geologists to Meet in Pittsburgh

Pennsylvania Geological Survey to Be Co-Sponsor of Teachers' Workshop

The Allegheny-Ohio Section of the Association of Engineering Geologists (AEG) will host the 33rd Annual Meeting of AEG from October 1 to 5, 1990, at the Hilton and Towers in Pittsburgh. The theme of this national meeting is "Engineering Geology for the 90's." The diverse program includes technical sessions, symposia, and short courses.

Technical sessions will focus on applied environmental and geological issues related to mine subsidence, hazardous-waste investigation and remediation, environmental geology, groundwater, slope stability, dams, karst, and erosion.

Two symposia are scheduled. One symposium will include 32 papers on the state-of-the-art prediction and control of mine subsidence. The other symposium will include 30 papers addressing the history of, need for, and current status of professional registration for geologists.

Four half-day short courses are scheduled concurrent with the Annual Meeting. They are "Environmental Applications of Engineering Geophysics," Sunday, September 30; "Applications of Microcomputers to Rock Slope Stability Analysis," Monday, October 1; "An Introduction to Geosynthetics: Selection, Design, and Applications to Waste Facilities," Monday, October 1; and "Site Characterization for Nuclear Waste Disposal," Thursday, October 4.

On Tuesday, October 2, the Pennsylvania Geological Survey, the University of Pittsburgh Department of Geology and Planetary Science, the Pittsburgh Geological Society, and the Allegheny-Ohio Section of AEG will sponsor a one-day Teachers' Workshop in conjunction with the annual meeting. Junior high and high school teachers will have the opportunity to broaden their understanding of geology, and will have hands-on experience in utilizing practical geological applications to compliment their environmental science curriculum. Teachers will also have the opportunity to receive Continuing Education Units through their participation in the workshop and meeting. Although teachers will be required to register for the workshop, they will not be charged a registration fee due to the generous financial sponsorship of the workshop by industry companies and organizations.

There will also be an Exhibit Program, which will be situated in an area centrally located to all meeting and function rooms. To receive a brochure and information for registration and exhibits, please contact AEG, MEMS, P. O. Box 270, Greensburg PA 15601, telephone 412-836-6813 (800-441-1674 in Pennsylvania; 800-343-5129 outside Pennsylvania).

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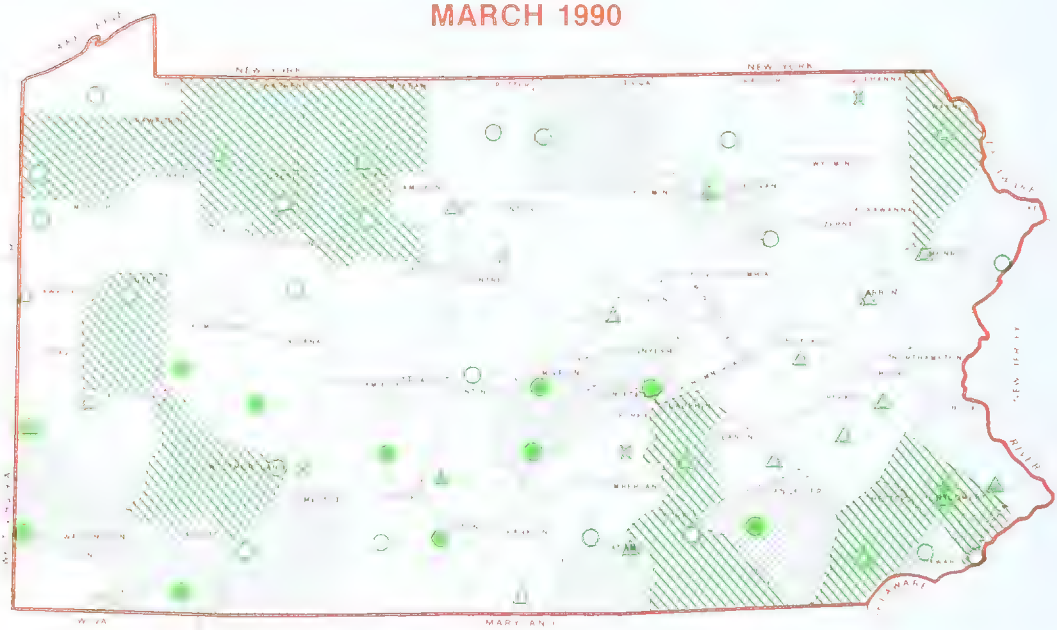

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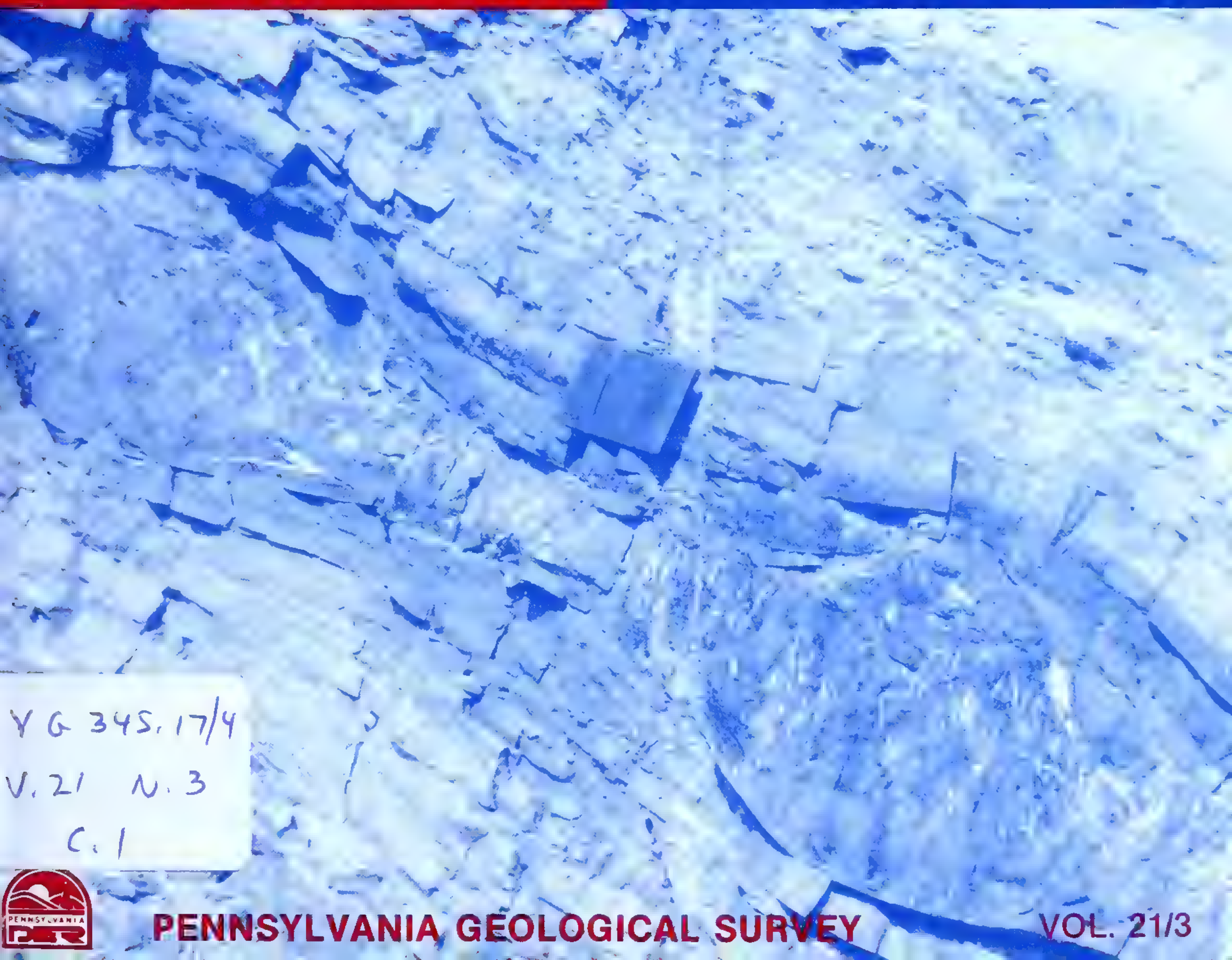

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ON THE COVER: Boudinage in the Union quarry at Rheems, in the northwest part of Lancaster County. Bedding dips moderately to the right. Most of the beds are limestones of the Lower Ordovician Epler Formation; the bed in the center filled with numerous white calcite veins is dolomite. These rocks have been greatly extended parallel to bedding. The limestones were ductile and thinned uniformly, whereas the dolomite, being more brittle, was extended inhomogeneously and developed boudinage structure. Where the extension was concentrated, the dolomite bed became very thin; the rocks between these necks underwent little extension and thus retained nearly their original thickness. The notebook is 21 cm long. Photograph by Rodger T. Faill.

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AUG 15 1990

The Beneficial Effects of Natural Disasters

In a recent article published in the *Journal of Irreproducible Results*, the author, Craig Bradley, with tongue in cheek, discusses the "challenging task of determining the beneficial effects of a major earthquake along the San Andreas Fault." While his article (volume 35, number 2, page 2) is humorous, it also has a very serious message, which is, he suggests, "to discover the good side of circumstances that cause only despair to others." Ben Franklin, a Pennsylvanian of some note, said it also in his adage, "the things that hurt instruct."

The "good side" is that each natural disaster teaches and reteaches us that only through attention to natural earth features such as steep colluvial slopes, areas of carbonate bedrock, and floodplains, and the dynamic earth systems that affect them, will we be able to safely design and build structures on which humans depend for daily existence. This requires data provided through careful, detailed, and accurate mapping of Pennsylvania's land surface and its weathered and unweathered bedrock. Knowledge of the three-dimensional relationships of Pennsylvania's land surface and its subsurface rocks, as well as their geophysical and geochemical characteristics, is critical for analysis.

Although we do not have to calculate the "beneficial" effects of a California-style earthquake for Pennsylvania, we do have to include in all construction plans and designs the likelihood of the occurrence of sinkhole collapse, landslides, or flooding. To ignore the "good side" lesson of natural disasters is folly. Similarly, we should cease considering such events as "acts of God." They are not; none are unique and all are frequently repeated in predictable locations. Pennsylvania's citizens and businesses, local governments, and the Commonwealth all repeatedly pay a large annual cost for ignoring the "beneficial effects of natural disaster" lesson, the lesson recognized by Franklin early in the development of Pennsylvania.

Donald M. Hoskins

Donald M. Hoskins
State Geologist

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OVERHEAD PROTECTION

Pennsylvania's Mineral Industry Contribution

by S. W. Berkheiser, Jr., and R. C. Smith, II
Pennsylvania Geological Survey

Generally, industrial minerals are like a good dog. They are quiet, resolute, trustworthy, economical, and do their duty without a lot of backlash. Most of the time, we are not even aware of the presence of industrial minerals, but they make life easier, more pleasant, and more enjoyable. Such is the case with roofing granules, those tiny, colored, ceramic-coated rock particles that are embedded in shingles. Collectively, they protect a great number of our houses from the effects of rain, sleet, and snow. This article concerns the operation of GAF Corporation, a member of Pennsylvania's mineral industry that began producing naturally colored roofing granules from metabasalt and metarhyolite for use in asphalt-based shingles in the 1920's. The plant and now-abandoned underground metabasalt mine that GAF purchased from The Blue Mountain Stone Company are located about 0.4 mile northwest of Gladhill, Pennsylvania, in southwestern Adams County.

HISTORY. Fiberglass-based shingles, embedded with artificially colored roofing granules, have evolved into the premier economical, fire-resistant, attractive roofing material used by the construction industry. The development of this complex, high-technology roof covering, now typically guaranteed to last 20 to 25 years, required years of research and experimentation. Humble beginnings, as early as 1780, involved attempts to find economical alternatives to slate, wood, and metal by using burlap saturated with pitch or tar (Jewett and others, 1983). Needless to say, these early attempts were far from satisfactory because they deteriorated rapidly and were expensive, difficult to work with, and ugly. They were also a major fire hazard!

A roof should not only be waterproof, but also fire resistant to help prevent fires from spreading from building to building. Early searches for suitable fire-resistant materials with which to armor the asphalt-saturated felt-base roofing materials led to the use of naturally colored source rocks. Initially, multicolored slate from New England was popular. The somber color of Pennsylvania's black and blue-gray slate led some producers to look to the greenstone and serpentine belts to find a more pleasing, nonfading green color (Stone, 1923). Among the many materials that have been tried over the years in the search for aesthetically pleasing roofing armor are silica sand, vein quartz, novaculite, feldspar, mica, greenstone, talc, glass, slag, basalt, granite, rhyolite, oyster shells, crushed bricks and tiles, and white porcelain (Jewett and others, 1983).

In the 1930's, the development of ceramic coatings changed the complexity and specifications of premium roofing granules by eliminating source rock color as a major consideration. According to Jewett and others (1983), the desirable properties for potential deposits of roofing granules today include the following:

(1) Resistance to weathering (eliminating carbonates and unsound rock from consideration);
(2) Adaptability to the coloring process (eliminating soluble rock and rock that does not have a porous surface);
(3) Uniformity of the deposit (assuring consistency of the finished product over a long period of time);
(4) Sufficient tonnage (allowing enough potential production over time to ensure a reasonable return on the initial capital investment);
(5) Low porosity (to prevent excessive absorption of coating chemicals, which could prove costly, or excessive adsorption of water, which might cause freeze-thaw deterioration);
(6) Opacity to ultraviolet light (to protect the base material from attack by solar radiation);
(7) Toughness (to minimize attrition); and
(8) Equidimensional fracturing upon crushing (together with blending, this assures a uniform color when the roof is viewed from different angles).

MINING. The West Ridge quarry of GAF is located on a northeast-southwest-trending ridge north of the Gladhill plant (Figure 1). The ore is mined from the Catoctin Formation, which here consists of a relatively uniform greenish-gray basalt metamorphosed to the green-

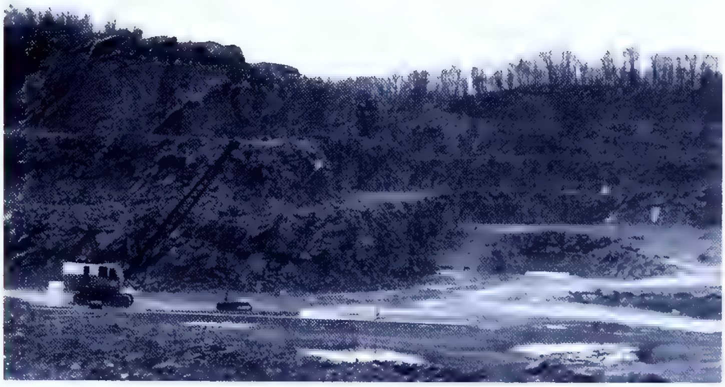

Figure 1. Southwest-looking view of the West Ridge quarry of GAF Corporation, showing the five levels of bench development. Faint southeast-dipping cleavage is visible in the near faces.

schist facies. Massive and amygdaloidal metabasalts are present in the area. Quarry control includes monitoring to avoid areas of high concentrations of iron, quartz (which has a smooth, nonporous surface and is transparent to ultraviolet light), epidote (which is hard to crush), and native copper. In addition, crushability tests for the minus 10 mesh (2.0 mm) to plus 35 mesh (0.5 mm) size fraction are closely monitored for minimum waste and maximum cubical particle shape (Nelson, 1968, and personal communication, 1988). Currently, GAF is developing a fifth quarry level using 40-foot-high quarry faces. Approximately 40 coreholes have helped to define a mining plan for potential quarrying down to a seventh level.

The Catoctin Formation is a series of metabasalts, phyllites, and metarhyolites located in the Blue Ridge physiographic province of Pennsylvania (Fauth, 1978). According to Badger and others (1988), these rocks are approximately 570 million years old, making them Late Precambrian in age. This sequence is more or less continuous to the south through Maryland and Virginia. The geologic setting has been interpreted to represent a series of extrusive igneous flows (locally submarine) and tuffs, associated with extensional rifting of continental plates that resulted in the opening of the Iapetus Ocean basin (Badger and others, 1988). Preliminary analyses of Catoctin metabasalts from the Gladhill area are listed in Table 1. Comparison of some trace-element ratios with those from relatively young basalts that are known to have formed in particular environments, such as an island-arc environment, along a mid-ocean ridge, or within a continental plate, suggests that the Catoctin metabasalt in this area formed within a plate.

Table 1. *Preliminary Analyses of Two Samples of Catoctin Metabasalt from the Gladhill Area, Adams County*

(Quantities are percentages)

	Sample 1	*Sample 2*
SiO_2	44.06	44.41
Al_2O_3	15.04	17.26
Fe_2O_3	14.20	13.41
CaO	9.85	8.49
MgO	6.92	7.73
Na_2O	2.35	1.79
K_2O	.31	.84
TiO_2	2.02	1.64
MnO	.21	.19
P_2O_5	.25	.16
Total	95.21	95.92

MANUFACTURING. Although the natural color, transportation network, and proximity to potential markets were original factors in GAF's site selection process in the 1920's, before the development of ceramic coatings, the green metabasalt of the Catoctin Formation is still quarried because of its adaptability to the silicate-clay coloring process (Figure 2). The quarry rock is initially reduced in a jaw crusher and further reduced in a series of gyratory crushers. Roll crushers prepare the final gradation of minus 10 mesh to plus 35 mesh, which is stored

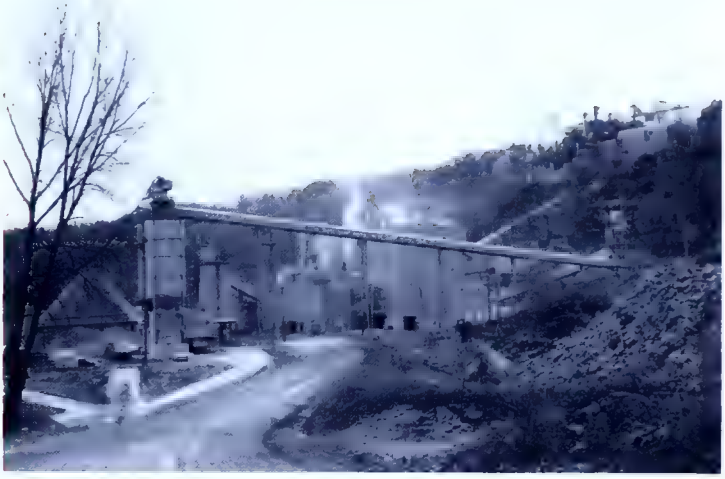

Figure 2. Northwest-looking view of the roofing-granule manufacturing complex of GAF Corporation. The crushing and sizing plant is in the foreground, and the coloring plant is higher on the hill in the background.

in silos. The ceramic coatings, which are based on a sodium silicate flux and a kaolin binder combined with inorganic pigments, are applied in a rotary mixer. The mixture is fired in a rotary kiln. The cooled and coated granules are screened again to remove agglomerates and are stored in silos. Fifteen different colors of granules are manufactured at Gladhill. There are two production lines in the coloring plant, and approximately 80 percent of all granules sold or used are color coated. The natural granules are used primarily for the headlap (covered) portion of the shingle. The newer fiberglass-based shingles require more granules than the older asphalt-felt-based shingles.

MARKETING. The primary product of the Gladhill operation is artificially colored roofing granules manufactured for shingle coatings. Most shingles are coated with a blend of several distinct granule colors. Earth tones have been in vogue for the past decade, whereas reflective, light hues are popular in warm climates. Most of the prepared granules are transported to GAF's shingle-manufacturing plants in Maryland and Massachusetts by 100-ton bulk railcars and to a lesser extent by 25-ton haul trucks. Granules are also sold to competing shingle-manufacturing plants in Delaware, Georgia, Maryland, New Jersey, North Carolina, and Pennsylvania.

The fine-grained by-product, or "tails," of this operation is put to a number of innovative uses. Some is used as a mineral filler in the shingle base and as an inert mineral filler in portland cement. It also finds use in walkways in the Gettysburg National Military Park, as colorants in the manufacture of bricks, and in cushions supporting pipelines and underground storage tanks. In what may be one of the most surprising and innovative uses, binder is added to sized by-product material, and the mixture is used as a 6-inch-thick top dressing for clay-based tennis courts.

GAF Corporation is another good example of the many industrial-mineral producers that work behind the scenes to contribute to the improvement of our way of life while collectively contributing more than $1 billion annually to Pennsylvania's economy.

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Geologic Structures and Metamorphism: Mapping the Elusive Isograds in the Pennsylvania Piedmont

by David W. Valentino and Rodger T. Faill
Pennsylvania Geological Survey

INTRODUCTION. Many of the rocks in the Piedmont province in southeastern Pennsylvania were once hot, and their minerals show it. Beginning as shales, sandstones, graywackes, and various other rock types, they were progressively buried by younger sediments, or tectonically covered by large thrust sheets. The heat and pressure during this deep burial transformed the clays and rock fragments into entirely new assemblages of minerals—they were metamorphosed and deformed. Erosion over the ensuing millions of years has returned these rocks to the surface where we can observe them. They tell quite a story!

As a rock is heated, it undergoes a sequence of mineralogic changes, which are grouped into three facies: greenschist, amphibolite, and granulite. Each facies represents an approximate range of temperatures and pressures within which a particular assemblage of minerals forms or exists (Figure 1). By identifying the minerals in a specific rock, the locality where the rock occurs can be assigned to the appropriate facies; and by assembling locality identifications from across the Piedmont, we obtain a map of metamorphic zones (Figure 2). This map shows the areas that have undergone only greenschist (low-grade) metamorphism as well as the areas at higher grades. Each of the lines (isograds) separating adjacent areas is defined by the first occurrence of the higher grade mineral when mapping from areas of lower to higher grade. The isograds are also defined by the disappearance of the higher grade mineral when mapping from areas of higher grade to areas of lower grade. Thus the biotite-garnet isograd (Figure 2) represents the first discovery of garnet during field mapping in the direction of increasing metamorphic grade.

The rocks of the highest metamorphic grade, the granulite facies, are present only in the eastern Piedmont. These areas are generally surrounded by rocks at the next lower grade, the amphibolite facies; a tongue of amphibolite facies rocks also extends across the western

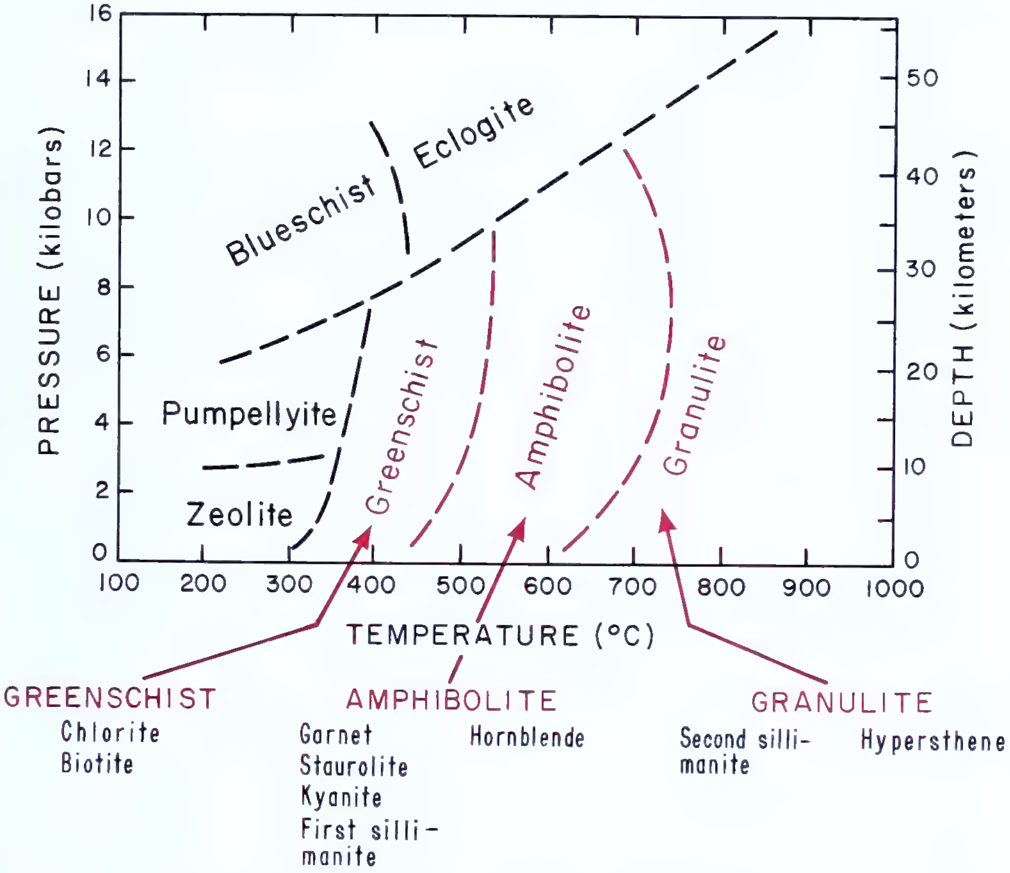


Figure 1. Diagram showing the relative positions of the various metamorphic facies with respect to approximate temperature and pressure, and a listing of metamorphic minerals associated with the metamorphic facies mapped during this investigation. Modified from Dietrich and others (1982).

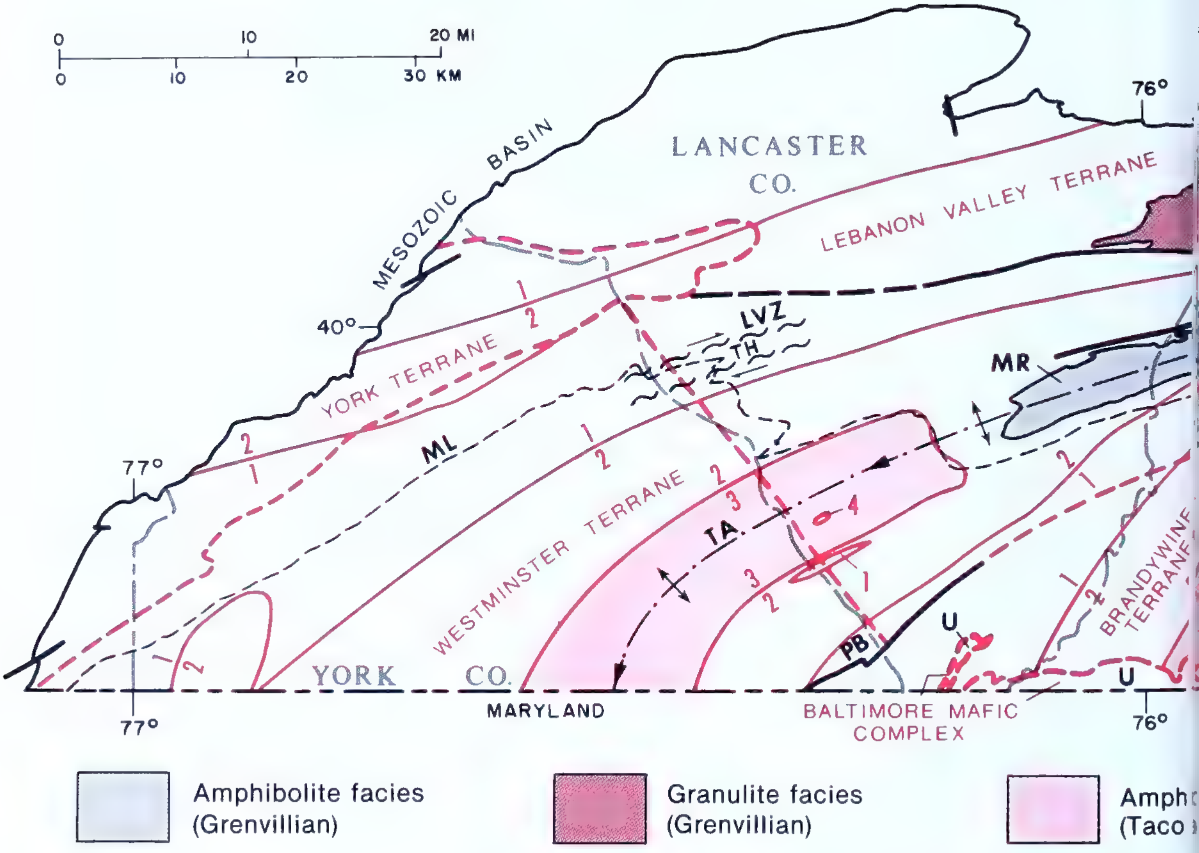
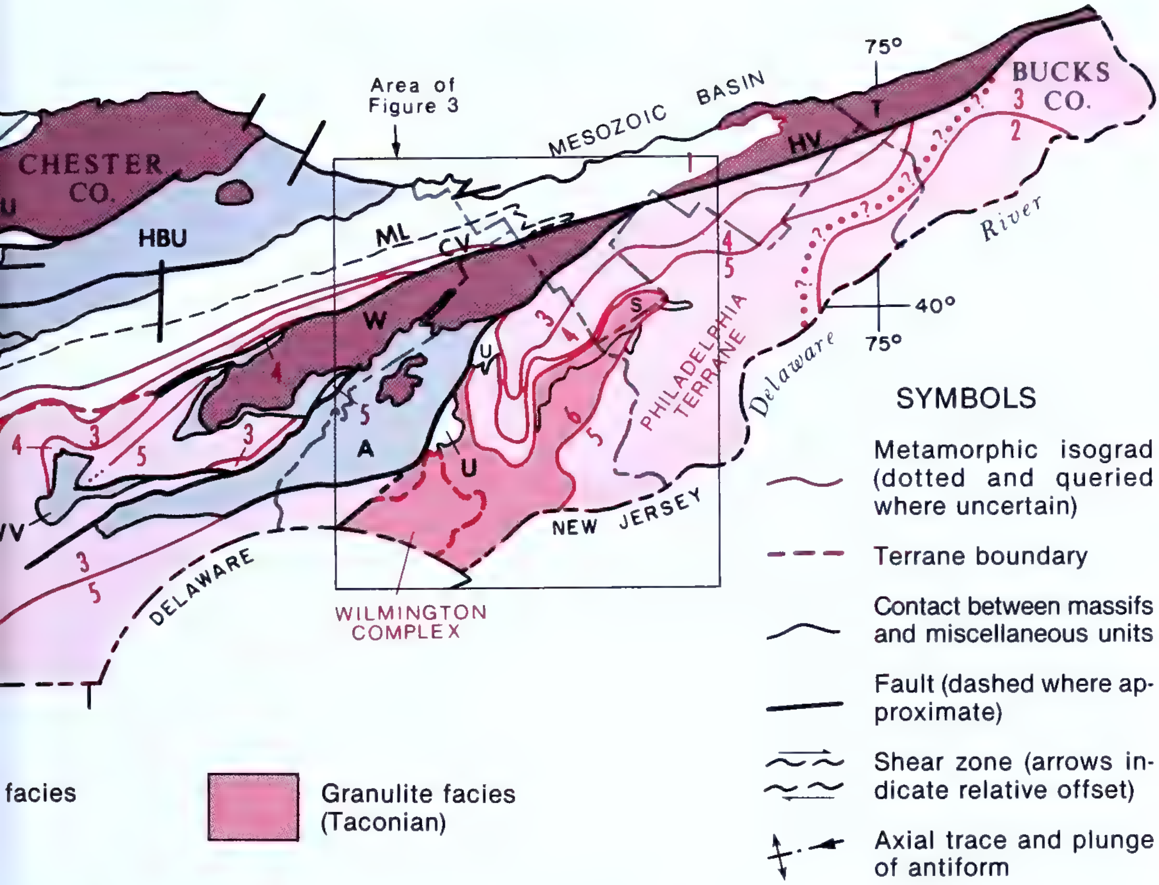


Figure 2. Map of the Pennsylvania Piedmont showing structures, terrane bounda
Structures: CV-HV, Cream Valley-Huntingdon Valley fault zone; LVZ, Lancaster Valle
Turkey Hill shear zone.
Grenvillian massifs: A, Avondale massif; HBU, Honey Brook Upland massif; MR, M
Miscellaneous units: S, Springfield gneiss; U, ultramafic rocks.
Minerals that define isograds: 1, chlorite; 2, biotite; 3, garnet; 4, kyanite; 5, first si

Piedmont. The remaining areas, in both the eastern and western Piedmont, are at the greenschist facies.

But the story is not quite as simple as the map suggests. One metamorphism affecting all of the Piedmont rocks cannot explain all of the features on the map; rather, we find that four metamorphic episodes have occurred, each one quite different, and each affecting different parts of the Piedmont.

METAMORPHIC EPISODES. *Grenvillian Metamorphism (M1).* The Grenville terrane contains evidence for the oldest metamorphism, which occurred about 1,000 million years ago (Ma) (Grauert and Wagner, 1975) and is represented by several separate massifs: the Honey Brook Upland, Mine Ridge, Trenton, West Chester, Avondale, and Woodville massifs. The rocks of all of these bodies were meta-


Area of Figure 3
75°
MESOZOIC BASIN
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40°
75°
NEW JERSEY
DELAWARE
WILMINGTON COMPLEX
WV
SYMBOLS
Metamorphic isograd (dotted and queried where uncertain)
Terrane boundary
Contact between massifs and miscellaneous units
Fault (dashed where approximate)
Shear zone (arrows indicate relative offset)
Axial trace and plunge of antiform
facies
Granulite facies (Taconian)

renvillian massifs, and metamorphic isograds.
onite zone; ML, Martic Line; PB, Peach Bottom structure; TA, Tucquan antiform; TH,

idge massif; T, Trenton massif; W, West Chester massif; WV, Woodville massif.

ite; 6, second sillimanite.

morphosed (M1) during the Grenvillian orogeny (Wagner and Crawford, 1975; Crawford and Hoersch, 1984; Hoersch and Crawford, 1988), and most of the rocks were metamorphosed to granulite facies (Figure 1), except for the rocks of Mine Ridge and the southern half of the Honey Brook Upland, which only reached amphibolite facies (Crawford and Hoersch, 1984; Hoersch and Crawford, 1988).

Taconian Metamorphism (M2). The metamorphism produced by the Taconian orogeny (dated at approximately 440 Ma by Grauert and Wagner, 1975) affected all of the Piedmont rocks, albeit to differing extents and grades. During this orogeny, diverse terranes (the Lebanon Valley, York, Westminster, Brandywine, and Philadelphia terranes, the Wilmington Complex, and the Grenvillian massifs (Faill and MacLachlan, 1989); see Figure 2) were emplaced in the present Piedmont province, generally in the relative positions they occupy today. The elevated temperatures that accompanied the Taconian orogeny metamorphosed all of the rocks involved, but the metamorphism was not uniform across the Piedmont. The range of metamorphic grades extends from lower greenschist to upper amphibolite facies. Furthermore, this metamorphic episode persisted for a long time. Radiometric ages, which represent dates when the rocks were cooling, indicate that this episode lasted for 100 million years after the peak of the Taconian orogeny.

The occurrence of the higher grade rocks at the present surface is a consequence of tectonism that followed the Taconian orogeny. For example, Taconian metamorphic isograds are symmetrically disposed on either side of the Tucquan antiform hinge, ranging from garnet grade (locally kyanite grade) in the hinge outward through biotite zones (Faill and Valentino, 1989). The tectonism responsible for this antiform has been dated at 320 Ma (Lapham and Basset, 1964) by means of the associated retrograde greenschist facies metamorphism in the limbs of the antiform. This pattern suggests that (1) the Taconian isograds continued over the crest of the Tucquan antiform; and (2) the original Taconian metamorphic isograd surfaces were probably near horizontal prior to post-Taconic uplift.

Southwest of the Tucquan antiform is a broad-trending zone of lower greenschist facies (chlorite-grade) schist and phyllite that extends across southern Lancaster County and southwestern Chester County, within which lies the Peach Bottom "syncline." This chlorite-grade zone becomes narrower to the east, occupying only the Chester Valley and South Valley Hills in central Chester County. The metamorphic gradient south of this chlorite zone becomes steeper to the east (the isograds become closer together), a trend that continues farther eastward into Montgomery County.

Southward and eastward, around the Brandywine massifs, the metamorphic grade increases to the kyanite zone of the amphibolite facies in the rocks closest to the Precambrian massifs. This increase in grade through progressively older rocks is probably a consequence of deeper burial, but the Taconian tectonism likely supplied the additional heat that enhanced the metamorphic grade. No such similar increase has been observed surrounding the Honey Brook massif, although some of the rocks adjacent to Mine Ridge were elevated to the lower amphibolite facies (garnet grade; areas are too small to be shown on Figure 2).

The highest grade rocks in the Philadelphia terrane follow a northeast trend that includes the Springfield gneiss. Metamorphic grade decreases to the northwest and east, to as low as upper greenschist facies east of Philadelphia.

Metamorphism of the Wilmington Complex (M3). The Wilmington Complex (a lower portion of an island arc) was thrust over the Philadelphia and Brandywine terranes, probably during the early stages of the Taconian orogeny (Wagner and Srogi, 1987). Because the complex was already hot, it and the immediately surrounding rocks were elevated to granulite facies (Figure 3). This effect decreased away from the complex, so that at some distance the metamorphism resulting from the emplacement of the complex merged with the Taconian metamorphism and they became indistinguishable.

Retrograde Metamorphism (M4). A probably long period of multiple episodes of retrograde metamorphism followed the largely concurrent Taconian and Wilmington Complex metamorphisms (M2 and M3). Retrograde metamorphism occurred where the rocks (previously metamorphosed during the Grenvillian or Taconian orogenies) were deformed in post-Taconian shear and tectonite zones (Rosemont, Crum Creek, Cream Valley-Huntingdon Valley, and Lancaster Valley). Metamorphic conditions accompanying the formation of these structures allowed for the growth of new lower grade minerals at the expense of the higher grade minerals primarily within the zones of deformation. Therefore, each retrograde episode generally represents a tectonic activity following the peak of Taconian metamorphism, in which deformation allowed for reequilibration of the mineral assemblages under conditions of lower temperature and/or pressure.

The earliest episode (M4a) centered on the Rosemont and Crum Creek shear zones (Valentino, 1988; Valentino, Richard, 1989). Across both of these zones, the Taconian isograds have been severely deflected (Wyckoff, 1952), indicating considerable retrograde metamorphism and post-Taconic offset associated with the zones (Figure 3). Wagner and Crawford (1975) recognized an amphibolite facies retrogression that accompanied mylonite development in the granulite-grade gneisses along the northern edge of the West Chester massif, adjacent to the Cream Valley fault zone (Figure 3).

The broad chlorite-grade zone in southern Lancaster County (Figure 2) continues eastward across eastern Chester County and Montgomery and Bucks Counties as a narrow chlorite-grade zone bounded on the south by the Cream Valley and Huntingdon Valley faults. It has been proposed that this narrow eastern part of the zone (in Chester Valley and the South Valley Hills) represents a later, second episode of retrograde metamorphism (M4b) concentrated along an east-northeast-striking, steeply dipping shear zone (Myer and others, 1985; Hill, 1989). The steep metamorphic gradient just to the south was probably generated during the first retrograde episode (M4a), but the cutoff of isograds by the Cream Valley fault movements may have been coincident with the shear zone movements and associated green-

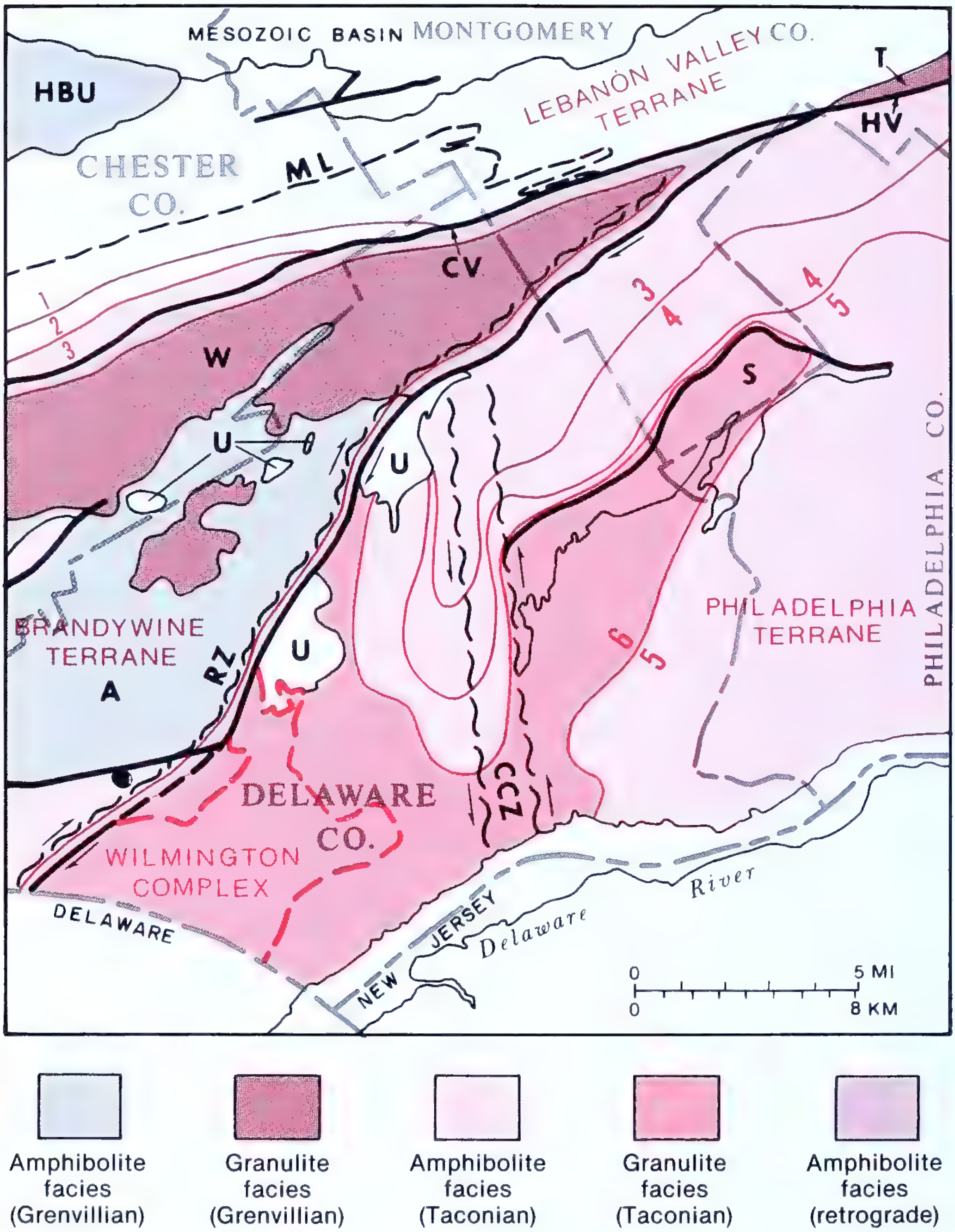

Figure 3. Map of the area west of Philadelphia showing the local structures, metamorphic isograds, terrane boundaries, and Grenvillian massifs. Structures: CCZ, Crum Creek shear zone; RZ, Rosemont shear zone. Refer to Figure 2 for an explanation of the other labels and symbols.

schist retrograde metamorphism. Whether or not this retrograde metamorphism continued southwestward, following the chlorite zone across southern Lancaster County, is simply not known at this time.

A third episode of retrograde metamorphism (M4c) is evident in the western Piedmont of Pennsylvania, in the vicinity of the Susquehanna River. The chlorite-grade zone on the north limb of the Tucquan antiform is actually retrograde from Taconian biotite grade. This broad zone of chlorite retrogression coincides with the Lancaster Valley tectonite zone (Valentino and MacLachlan, 1990) and the Turkey Hill shear zone, in which the north limb of the Tucquan antiform has been sheared (Valentino, 1989, 1990). Correlation of this retrograde zone with the Lancaster Valley tectonite zone and Turkey Hill shear zone indicates a post-Taconian age for these structures, and the deformation is probably synchronous with the differential uplift (Freedman and others, 1964) that produced the Tucquan antiform.

CONCLUSION. Compilation of published and new metamorphic data to produce an isograd map for the Piedmont province of Pennsylvania has revealed numerous structural aspects of the geology, as previously discussed. Recognition of the close relationship between metamorphic episodes and structures has enabled us to better correlate structures with the numerous orogenic episodes that occurred in the central Appalachian orogenic belt.

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NEW PUBLICATIONS OF THE PENNSYLVANIA GEOLOGICAL SURVEY

OIL AND GAS DEVELOPMENTS IN PENNSYLVANIA IN 1988

The latest report on the oil and gas industries in Pennsylvania provides valuable information to members of these industries, academia, and the general public. Data on production, reserve estimates, drilling and completions, and exploratory and development activities are presented by authors John A. Harper and Cheryl L. Cozart in tables and graphs which are both understandable and comprehensive. The "why's" for the 14.9 percent decline in oil production from 1987 to 1988 (3,301,763 to 2,807,003 barrels) are discussed, as are the reasons for the 2.3 percent upswing in gas production (163,318 to 167,089 million cubic feet) during the same time period.

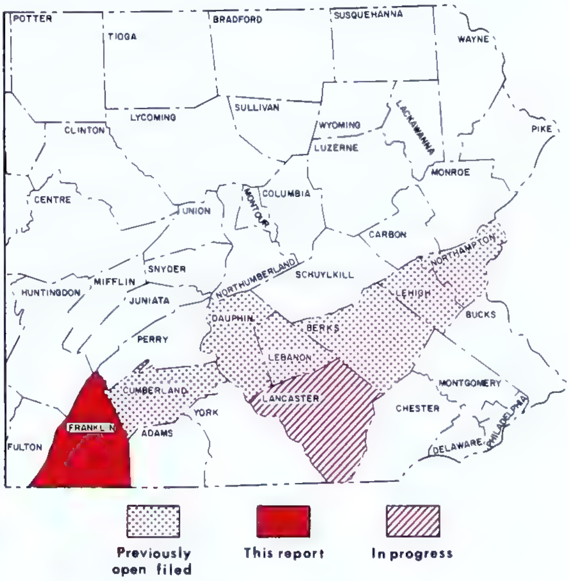
Warren County in northwestern Pennsylvania remains the most active county for oil well drilling. The most active counties for gas well drilling include Venango, Erie, Crawford, Indiana, Warren, Armstrong, and Clearfield.

Progress Report 202, **Oil and Gas Developments in Pennsylvania in 1988**, is available for $3.25, plus $0.20 sales tax for Pennsylvania residents, from the State Book Store, P.O. Box 1365, Harrisburg, PA 17105. Orders must be prepaid; please make checks payable to *Commonwealth of Pennsylvania*.

—*P. F. Buis*

OPEN-FILE REPORT ON SINKHOLES OF FRANKLIN COUNTY

The Pennsylvania Geological Survey announces the release of Open-File Report 89-03, **Sinkholes and Karst-Related Features of Franklin County, Pennsylvania**, by staff geologist William E. Kochanov. This report is part of a series designed to indicate areas of known sinkhole occurrence and potential sinkhole development. Environmental problems associated with sinkhole subsidence in the carbonate rocks of central and southeastern Pennsylvania have dramatized the need for greater understanding and information about weathering processes in carbonate bedrock and how these processes can affect bedrock stability in building and construction areas.



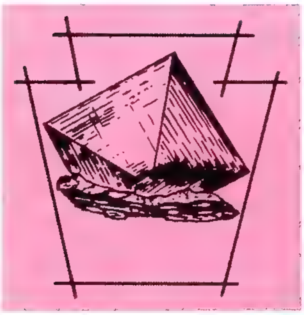
The report consists of nineteen 7.5-minute topographic maps (scale 1:24,000) and a brief text. The maps depict known sinkhole occurrences, carbonate geology, past and present surface mine locations, caves, and other karst-related features having surface expression. Similar reports have been prepared for Northampton, Lehigh, Berks, Lebanon, Dauphin, and Cumberland Counties.

In conjunction with the maps, a comprehensive computer data base is being developed at the Survey to store available sinkhole data (locations, physical characteristics, and methods of repair). The compilation of these data will provide a quick and useful source of additional background information for planning and land development in areas of carbonate bedrock.

Open-File Report 89–03 should be of considerable interest to county and municipal planning groups, engineers, state and federal agencies, and residents of Franklin County.

The Franklin County open-file report may be examined at the Survey's offices on the 9th floor of the Executive House, 101 South Second Street, Harrisburg, or copies of the report may be purchased by mail at the prepaid copying and shipping cost of $47.50 from the Bureau of Topographic and Geologic Survey, Department of Environmental Resources, P.O. Box 2357, Harrisburg, PA 17105. Pennsylvania residents should include $2.85 sales tax. Please make checks payable to *Commonwealth of Pennsylvania*.

—*W. E. Kochanov*



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The American Geological Institute (AGI) has issued a new communication service for earth science teachers. Prepared by the National Center for Earth Science Education of AGI, it is called *Earth Science Education Connection*. The object of *Connection* is to "foster advocates for Earth science education, and provide a forum for scientists and educators to exchange ideas and information that affect it." *Connection* will be published quarterly (volume 1, number 1 was issued as the Summer 1989 edition) and will be distributed free of charge. To receive the newsletter, write to the editor, Mark T. Schmidt, American Geological Institute, 4220 King Street, Alexandria, VA 22302–9990.

Resources for Earth Science Teachers–1989

AGI has also issued a four-page compilation of earth science references and enrichment materials, including catalogs, publication lists, teachers' packets, books, and journals. Write to AGI at the above address for a copy of this listing.

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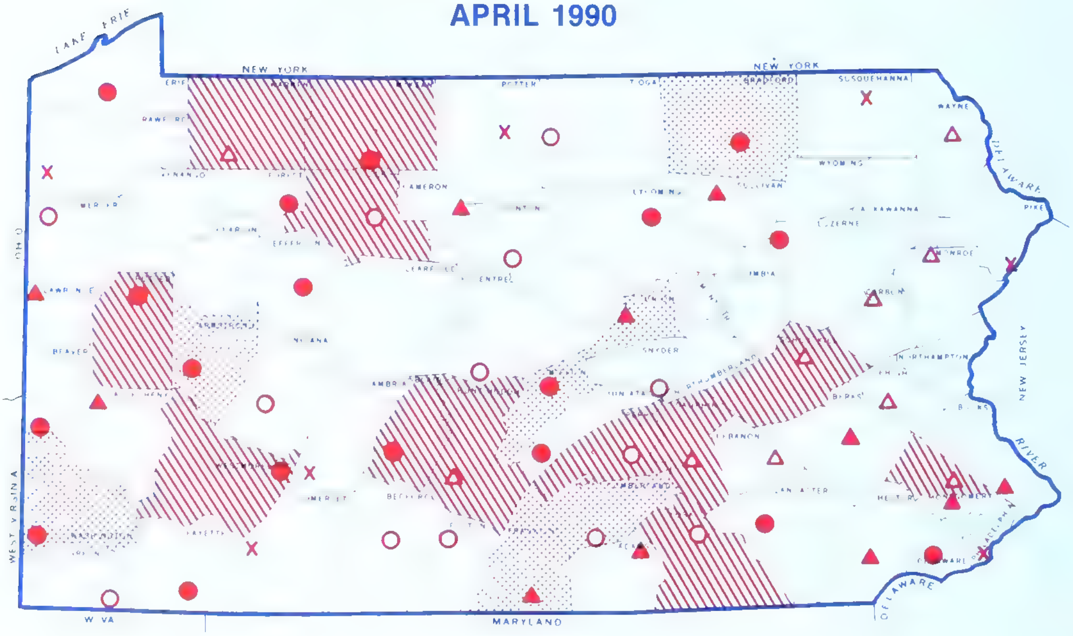

EXPLANATION

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PENNSYLVANIA GEOLOGICAL SURVEY VOL. 21/4

COMMONWEALTH OF PENNSYLVANIA
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ON THE COVER: The Susquehanna River at Dauphin—"a mile wide and a foot deep." Ledges in the river in the near foreground are overturned Mississippian-age Pocono sandstone, which also underlies the linear ridge (with gap) in the background. The middle ground and river ledges are underlain by much less resistant sandstone of the Mauch Chunk Formation, which forms the core of the Cove Mountain syncline outlined by the Pocono sandstone. In the far background (seen through the gap) are Middle Devonian sandstones on Dicks Ridge; on the horizon is Tuscarora Mountain, which is underlain by Silurian-age sandstones. The evenly spaced features in the foreground are the piers of a bridge destroyed by one of the frequent floods of the Susquehanna River. Photograph by T. A. McElroy.

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OCT 12 1990

Peat To Cleanse Toxic Waste

A recent report on the use of peat, an industrial "mineral" found in all 50 states and in most other nations, is the impetus for this preface to the annual report of geologic research in Pennsylvania. *Geotimes* (July 1990, p. 10) contains a report on current research that suggests "peat may be the cheapest effective material to clean up toxic-waste sites across the country. . . ." If this research on the use of peat is fruitful, new controversy may occur between mineral producers and those desiring to protect our natural environment, and perhaps even among environmental protection specialists themselves.

In the past few years, there has developed a public realization of the need to protect wetlands because of their importance as a habitat for flora and fauna, for recharge to aquifers, and for natural flood control. Our nation has established a goal of no net loss of wetlands; regulatory programs are being developed to assist in achieving this goal. Peat in Pennsylvania occurs in wetlands and is the result of thousands of years of accumulation of plant material in wet, boggy areas that remained after the landscape of parts of northern Pennsylvania was rearranged by huge continental glaciers.

The development and management of a protection policy for Pennsylvania wetlands must include consideration of the implications of the new research on peat. The environmental "value" of peat as a potential medium for cleansing toxic waste will have to be balanced against the environmental "value" of maintaining wetlands for their other beneficial purposes and uses. And each must be weighed against the economic value of peat as a mineral commodity.

The complexity of the earth's natural systems requires that we continually conduct geoscience research and, based on the results of that research, continually modify our understanding of those systems. Only in this way can we manage and regulate our human activities to achieve the highest environmental value and reach our economic goals. With forethought, we may sometimes be able to simultaneously achieve several goals—produce an economic mineral resource and preserve or enhance the environment—thereby creating a greater benefit than by focusing on only one goal.

Donald M. Hoskins

Donald M. Hoskins
State Geologist

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GEOLOGICAL RESEARCH IN PENNSYLVANIA
1990

Introduction

This publication, the thirty-third annual report in its series, contains a listing of all known current geological research in Pennsylvania and all known reports published during the past year pertaining to Pennsylvania geology. Because of the large number of projects reported to us, we editorially condense the descriptions to fit available space.

We have requested that each person estimate an anticipated completion date (ACD) for each project. The anticipated completion date is the author's estimate of the date when the project will be finished; additional time should be allowed for publication of the report.

If you wish to obtain more information on a project described herein, please write directly to the author; most of these projects will not be published by the Pennsylvania Geological Survey inasmuch as most are not Survey-sponsored projects.

The listings are grouped into major categories of research to facilitate your search for information on a particular subject. As with all compilations, there may be omissions; this is unintentional.

Additional copies of this report may be obtained by writing to the Pennsylvania Geological Survey, P. O. Box 2357, Harrisburg, PA 17105-2357.

Areal Geology

T. M. BERG, Ohio Geol. Survey, and C. M. DODGE and J. D. INNERS, Pa. Geol. Survey. **Map 61, Atlas of Preliminary Geologic Quadrangle Maps of Pennsylvania** (2nd ed). The popular "Map 61 Atlas" is being revised to include all quadrangles of Pennsylvania, and many corrections, additions, and changes are being included. The new edition will provide users with a single, desktop source for all of the bedrock geology of the Commonwealth. ACD: 1992.

T. M. BERG, Ohio Geol. Survey, W. D. SEVON and M. E. MOORE, Pa. Geol. Survey, and M. L. O'NEAL, C. B. CUBBISON, JACQUELINE LUNDY, and J. B. LESSMAN (all student interns, Pa. Geol. Survey). **Geologic Map of Warren County.** Bedrock and surficial maps are being prepared for the Warren County groundwater report, a cooperative project of the Pennsylvania Geological Survey and the U.S. Geological Survey, Water Resources Division. ACD: 1990.

J. B. EPSTEIN and P. T. LYTTLE, U.S. Geol. Survey. **Geology of the New Tripoli and New Ringgold Quadrangles.** Mapping of bedrock and surficial deposits; structural interpretation of Great Valley and Valley and Ridge; reinterpretation of Martinsburg stratigraphy. ACD: New Tripoli quad., June 1990; New Ringgold quad., Oct. 1991.

R. T. FAILL, Pa. Geol. Survey. **The Peach Bottom Structure, York County.** A 6- to 7-km-wide swath centered on the Peach Bottom slate is being mapped in detail to ascertain the origin of the slate, its relationship to the surrounding Cardiff conglomeratic quartzite and Peters Creek quartzose schist, and the overall structural setting. ACD: March 1991.

P. C. LYONS and W. F. OUTERBRIDGE, U. S. Geol. Survey, and E. S. BELT, Amherst Coll. **Late Paleozoic Depositional and Coalification Processes.** The project is a regional stratigraphic study of the Middle and Upper Pennsylvanian of the central and northern Appalachian basin using marker beds (marine units, volcanic units (tonsteins), coal beds, flint clays, etc.) for stratigraphic synthesis. The dynamic elements of the basin—sedimentation, tectonism, and coalification—will be examined in relationship to the Alleghanian orogeny. ACD: Sept. 1994.

D. B. MacLACHLAN, Pa. Geol. Survey. **Geology of the Freeburg Quadrangle, Snyder County.** Mapping of the Tuscarora-to-Catskill section on the nose of the Shade Mountain anticline and in the Northumberland syncline. Mapping is field complete; compilation of surficial units is currently on hold. Maps are scheduled to be placed on open file in 1991.

D. B. MacLACHLAN, Pa. Geol. Survey. **Lower Paleozoic Rocks of Platformal to Marginal Facies in the Pennsylvania Piedmont.** Field reconnaissance of stratigraphic and lithologic relations of the Chilhowee Group to Middle Cambrian rocks has been conducted from the Susquehanna River eastward through most of Lancaster County and is being continued into Chester and Montgomery Counties. The objective is to clarify the pre-Taconic structure of the Lower Paleozoic carbonate bank edge and identify areas where detailed remapping is urgently required. Preliminary report is scheduled to be placed on open file in late 1990.

W. D. SEVON, Pa. Geol. Survey. **Surficial Geology of the Conestoga and Holtwood Quadrangles, Lancaster and York Counties.** ACD: 1990.

W. D. SEVON, Pa. Geol. Survey. **Surficial Geology of the Quarryville, Wakefield, Kirkwood, and Gap Quadrangles, Lancaster and Chester Counties.** ACD: 1991.

D. W. VALENTINO, Pa. Geol. Survey. **The Peach Bottom Structure, Lancaster County.** The Cardiff conglomeratic quartzite comprises three lenses that do not wrap around the eastern end of the Peach Bottom slate. This lithologic distribution does not support the synform model of earlier workers. ACD: Aug. 1990.

Economic Geology

P. H. BENOIT AND C. B. SCLAR, Lehigh Univ. **An Electron Microprobe Study of Chromite Deposits of the Pennsylvania-Maryland State Line District with Particular Reference to the "Vein" Chromite of the Woods Mine.** Electron microprobe studies of the "vein" chromite from the Woods chrome mine show that the "vein" chromite has a different chemistry relative to the massive chromite. This difference may be due to the process of "ferritchromite" formation subsequent to emplacement of the " vein" chromite. It is doubtful that the chromite "veins" represent hydrothermal "vein" chromite, and it is also doubtful that the "veins" are igneous injections. ACD: May 1990.

S. W. BERKHEISER, JR., and R. C. SMITH, II, Pa. Geol. Survey. **Additional Occurrences of Specialty-Use Silica in Pennsylvania.** A 700-foot core from Adams County will be logged by E. L. Simpson of Kutztown University.

C. H. DODGE, Pa. Geol. Survey. **Coal Resources of Elk County—Part 1, Coal Crop Lines, Mined-Out Areas, and Structure Contours.** Detailed geologic mapping of the coal-bearing strata (Pottsville, Allegheny, and Glenshaw Formations) of Pennsylvanian age. Emphasis is on the major coal-bearing structural basins. A series of maps will be prepared including (1) separate crop-line maps for each principal coal seam showing areas of strip and deep mining, and (2) composite maps showing the crop lines of major and minor coals, as well as structure contours and fold axes. ACD: 1992.

J. S. FOX and S. T. PEES, Samuel T. Pees and Assoc. **Density Porosity and Porosity Trends of Sandstones in the Cabot Head Formation, Medina Group, Portion of Northwestern Pennsylvania.** ACD: Dec. 1990.

A. D. GLOVER, Pa. Geol. Survey. **Coal Resources of Jefferson County—Part 1, Coal Crop Lines, Mined-Out Areas, and Structure Contours.** Published and unpublished data will be used to prepare a series of maps including (1) separate crop-line maps for each principal coal seam showing areas of strip and deep mining, and (2) composite maps showing the crop lines of all principal coals, as well as structure contours and fold axes. ACD: 1993.

A. D. GLOVER, Pa. Geol. Survey, and W. A. BRAGONIER, Rochester and Pittsburgh Coal Co. **Coal Resources of Armstrong County—Part 1, Coal Crop Lines, Mined-Out Areas, and Structure Contours.** Published and unpublished data will be used to prepare a series of maps including (1) separate crop-line maps for each principal coal seam showing areas of strip and deep mining, and (2) composite maps showing the crop lines of all principal coals, as well as structure contours and fold axes. ACD: 1991.

J. A. HARPER, Pa. Geol. Survey. **Oil and Gas Fields of Pennsylvania.** Revision of Pennsylvania Geological Survey Map 3, last published in 1982. ACD: 1992.

J. A. HARPER, **Oil and Natural Gas Pipelines of Pennsylvania.** Revision of Pennsylvania Geological Survey Map 62, last published in 1983. ACD: 1991.

J. A. HARPER and C. D. LAUGHREY, Pa. Geol. Survey. **Measuring and Predicting Reservoir Heterogeneity in Complex Deposystems—Cambrian and Ordovician Carbonates of Northwestern Pennsylvania.** ACD: Oct. 1992.

J. D. INNERS, Pa. Geol. Survey. **Anthracite Geology of the Hazleton Quadrangle, Luzerne, Carbon, and Schuylkill Counties.** Project mainly involves preparation of 1:12,000-scale coal-bed outcrop and structure-contour (Buck Mountain/Mammoth seams) maps of the anthracite basins in the Hazleton area of the Eastern Middle field. A 1:12,000-scale open-file surficial geology map is also being prepared. ACD: Indefinite.

L. J. LENTZ and P. F. BUIS, Pa. Geol. Survey. **Coal Resources of Greene County—Part 2, Overburden Thickness, Coal-Reserve Estimates, and Coal Quality.** Computer compilation and manipulation of coal data for Greene County continues. Data base includes point and line data, stratigraphic data, and chemical data stored in files managed by the U.S. Geological Survey in Reston, Virginia. ACD: Ongoing.

L. J. LENTZ and P. F. BUIS, Pa. Geol. Survey. **Coal Resources of Washington County—Part 2, Overburden Thickness, Coal-Reserve Estimates, and Coal Quality.** Computer compilation and manipulation of coal data for Washington County continues with the entry of new records and the updating of others. Data base includes point and line data, stratigraphic data, and chemical data stored in files managed by the U.S. Geological Survey in Reston, Virginia. ACD: Ongoing.

A. K. MARKOWSKI, Pa. Geol. Survey. **Preliminary Feasibility Study of the Coal-Bed Methane Resource in Pennsylvania.** Data from exploratory drill holes and pre-mining degasification/methane recovery test projects in 11 counties were compiled and analyzed. Variations in gas contents with other geologic controls are used in assessing economic viability. ACD: 1990.

S. T. PEES, Samuel T. Pees and Assoc. **Distribution of Cabot Head Formation Sandstones of the Lower Silurian Medina Group, Portion of Northwest Pennsylvania** [Crawford Co. and parts of adjacent counties]. Isopachs of Cabot Head Formation sandstones facilitate seeking geological trends and hydrocarbon reserves in this stratigraphic section. Buildups and lean areas become apparent. Medina Group drilling programs can be planned to incorporate these additional reservoirs. ACD: Sept. 1990.

S. T. PEES, Samuel T. Pees and Assoc. **Stratigraphy of the Gatesburg Formation and Distribution of Hydrocarbons in It and Older Beds, Northwestern Pennsylvania and Environs.** The Gatesburg Formation in northwestern Pennsylvania contains the Rose Run stratigraphic unit of Ohio as one of its members (Upper Sandy Member). Hydrocarbon shows are recorded in all four members and in the underlying Warrior Formation. ACD: Aug. 1990.

G. R. ROBINSON, JR., D. GOTTFRIED, A. J. FROELICH, AND J. SMOOT, U. S. Geol. Survey. **Metallogeny of the Early Mesozoic Basins of the Eastern United States** [area of the Newark and Gettysburg basins in Pennsylvania]. Maps (at 1:125,000 scale) showing the distribution of metallic mineral deposits and geochemical anomalies from the NURE data base relative to geologic units in the Gettysburg and Newark basins (geology supplied by Froelich and Smoot) are under compilation. ACD: Oct. 1990.

J. R. SHAULIS, Pa. Geol. Survey. **Coal Resources of Somerset County—Part 1, Coal Crop Lines, Mined-Out Areas, and Structure Contours.** Published and unpublished data will be used to prepare a series of maps including (1) separate crop-line maps for each principal coal seam showing areas of strip and deep mining, and (2) composite maps showing the crop lines of all principal coals, as well as structure contours and fold axes. ACD: 1990.

SMITH, R. C., II, Pa. Geol. Survey, A. K. SINHA, Va. Polytechnic Inst., and S. W. BERKHEISER, JR., and J. H. BARNES, Pa. Geol. Survey. **Trace-Element Content of Some Pre-Mesozoic Basaltic Rocks in Pennsylvania** [southeastern Pa.]. Two distinct compositions of Catoctin basalt flows appear to be present in the Reading Prong and Honey Brook Upland as dikes.

V. W. SKEMA, Pa. Geol. Survey. **Coal Resources of Clearfield County—Part 1, Coal Crop Lines, Mined-Out Areas, and Structure Contours.** Detailed geologic mapping of the coal-bearing strata of Pennsylvanian age. Emphasis is on the major coal-bearing structural basins. A series of maps will be prepared including (1) separate cropline maps for each principal coal seam showing areas of strip and deep mining, and (2) composite maps showing the crop lines of major and minor coals, as well as structure contours and fold axes. ACD: 1992 (first phase).

A. A. SOCOLOW, Consulting Geologist. **Market Analysis of Limestone Specialty Products** [eastern Pa.]. Assessment of market potential for proposed new carbonate products installation, with reference to domestic and foreign markets. ACD: Completed.

RON STANTON and BRENDA PIERCE, U. S. Geol. Survey. **Quality and Succession of Coal Facies** [part of west-central Pa.]. ACD: 1990-91.

Engineering Geology

R. P. BRIGGS, Geomega, Inc., CRAIG PARKE and WILLIAM JOHNSON, Rizzo Assoc., H. P. OSHEL and DAVID LIENHART, U. S. Army Corps of Engineers; W. R. ADAMS, JR., Pa. Dept. of Transportation, R. F. FONNER, W. Va. Geol. and Economic Survey, and others. **Field Trip Guide, 33rd Annual Meeting, Association of Engineering Geologists, Pittsburgh, 1990.** Field Trip 1—Cincinnati to Pittsburgh, with stops in Ohio and West Virginia (2 days); Field Trip 2—U. S. Bureau of Mines facility, Fayette County; Lake Lynn Dam repair (Monongalia County, W. Va.), airport and landfill (Allegheny County, Pa.) (1 day); Field Trips 3 and 4—Geology and engineering geology, chiefly in Allegheny County (½ day each). ACD: July 1990.

J. V. HAMEL, Hamel Geotechnical Consultants. **Bank Instability Along the Monongahela River in Southwestern Pennsylvania.** Bank failures are highly site specific and typically involve mass wasting (landslide) and piping (internal erosion) processes that break down bank soils, increasing their susceptibility to erosion by the river. ACD: Ongoing.

GREG MOLINDA, U. S. Bur. of Mines. **The Effect of Topography on the Stability of Underground Openings.** The project involves relating ground control problems in coal mines to surface topography by a statistical analysis of terrain (valley width, relief, valley orientation, depth of cover, valley shape factor) and its proximity to poor-quality roof. The goal is to determine if simple topographic measurements can be used to indicate the approach to unsafe roof conditions. ACD: Ongoing.

A. M. STERNAGLE, Pa. Dept. of Transportation. **Instability Problems Associated with the Tuscarora Formation in the Valley and Ridge Province of Central Pennsylvania.** Several major highway projects have been constructed in or near Silurian-age Tuscarora sandstone. Construction problems, some unique, occur within this formation. ACD: 1993.

Environmental Geology

M. R. BELL, CHARLES GEIGER, and C. K. SCHARNBERGER, Millersville Univ. **Geostatistical Analysis of the Occurrence of Radon in Lancaster County.** ACD: May 1990.

H. C. FRY, Univ. of Pittsburgh at Johnstown, and members of the Greater Johnstown Watershed Assoc. **Update of Water Quality of Stony Creek** [Somerset and Cambria Cos.]. A follow-up of studies made over 20 years ago by the U. S. Environmental Protection Agency and the Pennsylvania Department of Environmental Resources of the water quality of Stony Creek to determine what changes, if any, have occurred in the interim. ACD: Jan. 1991.

W. E. KOCHANOV, Pa. Geol. Survey. **Sinkholes and Karst-Related Features of Centre County.** ACD: Winter 1990–91.

W. E. KOCHANOV, Pa. Geol. Survey. **Sinkholes and Karst-Related Features of Lancaster County.** ACD: Summer 1990.

W. E. KOCHANOV, Pa. Geol. Survey. **Sinkholes, Karst, and Engineering Considerations in the Carbonate Terrains of Pennsylvania** [central and southeastern Pa.]. ACD: 1991.

A. W. ROSE, J. W. WASHINGTON, D. J. GREEMAN, and E. J. CIOLKOSZ, Pa. State Univ. **Generation and Mobility of Radon in Soils** [eastern U.S.]. Detailed measurements of soil gas radon at sites in Centre, Berks, and Bradford Counties show seasonal variations of 2- to 10-fold with high values in summer. Radium is enriched relative to uranium in vegetation and soil organic matter. ACD: July 1990 (this phase).

A. A. SOCOLOW, Consulting Geologist. **Municipal and Hazardous Wastes Site Evaluations and Screening** [eastern half of Pa.]. Assessment of geologic, hydrologic, and topographic conditions at designated sites, with particular reference to regulations of the Pennsylvania Department of Environmental Resources. ACD: Ongoing.

General Geology

A. L. HOERSCH, La Salle Univ., and C. G. WISWALL, West Chester Univ. **Guidebook to the Geology of the Philadelphia Area.** A revision of General Geology Report 41, originally published by the Pennsylvania Geological Survey in 1964 and written by B. K. Goodwin. ACD: 1990.

E. F. KOPPE, Consulting Geologist. **Coal Geology and Resources Between the Northern Anthracite Field and the Western Bituminous Coal Region of Pennsylvania** [Lycoming, Tioga, Bradford, and Sullivan Cos.]. ACD: Ongoing.

A. N. KOVEE, U. S. Geol. Survey. **U. S. Geological Survey Radar Acquisition Program** [Warren and Williamsport 1:250,000 quads.]. The acquisition of the Warren and Williamsport 1:250,000 radar image mosaic quadrangles completes side-looking airborne radar coverage of the entire state. A single compilation of radar data for the state is being planned at 1:1,000,000 scale.

P. B. MYERS, D. J. ANASTASIO, and M. J. PODNIESINSKI, Lehigh Univ. **Geology of Lehigh Tunnel #2, Pennsylvania Turnpike** [eastern Pa.]. Mapping of the sedimentological and structural characteristics during construction of Lehigh Tunnel #2 in the Martinsburg, Shawangunk, and Bloomsburg Formations. ACD: Sept. 1990.

Geochemistry

FRED BALDASSARE, Pa. Dept. of Environ. Resources, Bur. of Waste Mgmt., and C. D. LAUGHREY, Pa. Geol. Survey. **Stable Carbon ($^{13}C/^{12}C$) and Hydrogen (Deuterium) Compositions of Methane from Various Sources in Western Pennsylvania.** We are exploring the possibility of identifying methane from various sources (Upper/Lower Devonian gas, coal seams, landfills, methane associated with shallow groundwater, etc.) through stable carbon isotopic analyses. Twenty-three samples have been analyzed to date. ACD: Aug. 1991.

K. R. CERCONE, JOHN TAYLOR, and 1990 geochemistry class, Indiana Univ. of Pa. **Biogeochemistry of Fossil Invertebrates from the Brush Creek Marine Interval** [southwestern Pa.]. As a joint student-faculty research project, a comparative study of shell chemistry is being done on invertebrates from Johnstown and Shelocta outcrops of the Brush Creek. X-ray diffraction, trace-element chemistry, and stable-isotopic ratios are being used to determine the degree of original shell preservation and the process of recrystallization. ACD: June 1990.

C. D. LAUGHREY, Pa. Geol. Survey. **Oil and Gas Source Rocks in Pennsylvania.** The purpose is to identify the oil and gas source rocks in Pennsylvania utilizing data that document the amount, type, and maturation state of organic matter present in the Paleozoic and Mesozoic rocks of the state. ACD: Aug. 1990.

M. L. MORGART, Pa. Dept. of Environ. Resources, Bur. of Oil and Gas Mgmt. **The Effects of Road Spreading of Gas Well Brine on Local Groundwater** [southwestern Pa.]. Water samples are being collected using lysimeters installed along unpaved roads approved by the Commonwealth for brine spreading for dust control. The project goal is to determine the impact of brine spreading on the shallow groundwater environment. ACD: 1991.

M. L. MORGART, Pa. Dept. of Environ. Resources, Bur. of Oil and Gas Mgmt. **The Taylorstown Groundwater Study, Washington County.** Monthly samples were collected from 23 water wells for one year. Trilinear diagrams were used to determine effects of waterflooding for enhanced oil recovery on groundwater. Negative impacts observed were attributed to past improper surface brine discharges and not to waterflooding. ACD: Feb. 1990.

Geomorphology

P. H. DOUGHERTY, Kutztown Univ. **Investigation of Tectonic Caves in the Appalachian Province of Pennsylvania.** ACD: Ongoing.

DRU GERMANOSKI, Lafayette Coll. **Land Use Change and Accelerated Erosion in the Bushkill Creek Watershed, Northampton County.** ACD: Aug. 1991.

J. C. RIDGE, Tufts Univ., W. D. SEVON, Pa. Geol. Survey, and E. B. EVENSON, Lehigh Univ. **Wisconsinan Landscape Development Outside the Limit of Late Wisconsinan Glaciation in the Delaware Valley** [Northampton Co., Pa., and Warren Co., N. J.]. The project is designed to compile the evidence of landscape development not associated with the direct influence of glaciation. Of particular interest are the rates and processes responsible for the formation of colluvium aprons, soils, and periglacial landforms. ACD: 1991.

Geophysics

E. R. KING, Project Chief, U.S. Geol. Survey. **Development of Geophysical Techniques for Investigating Occurrence of Polymetallic Sulphides in the Eastern United States.** Magnetic, gravity, and radiometric expressions of sulphide deposits in the Blue Ridge and Piedmont provinces are being examined for possible diagnostic criteria for locating mineral resources. ACD: 1991.

K. P. KODAMA and JOHN STAMATAKOS, Lehigh Univ., and ART GOLDSTEIN, Colgate Univ. **Effects of Shear Strain on Remanence** [Ridge and Valley province in Pa. and Md.]. A detailed rock paleomagnetic and strain study of the Silurian Bloomsburg Formation shows that the previously reported Bloomsburg paleomagnetic pole may have been affected by strain. We derive a low strain pole more consistent with North American APW. ACD: Sept. 1990.

J. D. PHILLIPS and D. L. DANIELS, U. S. Geol. Survey. **Geophysical Mapping of Early Mesozoic Basins.** Preparation and interpretation of aeromagnetic and gravity maps for Mesozoic basins in the eastern United States, including the Newark and Gettysburg basins in Pennsylvania. ACD: Sept. 1990.

Hydrology

T. F. BUCKWALTER, U.S. Geol. Survey, and M. E. MOORE, Pa. Geol. Survey. **Groundwater Resources of Warren County.** Countywide groundwater conditions will be evaluated. Extensive water-quality data will be used to determine impacts of oil and gas production on the resource. A revised geologic map will be included. ACD: 1991.

JACK CROOK, Pa. Dept. of Environ. Resources, Bur. of Community Environ. Control. **Identification of Aquifers in Public Water Supply Wells** [northwestern Pa.]. ACD: June 1991.

P. H. DOUGHERTY, Kutztown Univ. **Impact of Urbanization on a Karst Aquifer in the Lehigh Valley: the Shantz Spring Basin.** ACD: Dec. 1991.

DRU GERMANOSKI, PAMELA BRAUNWELL, and JASON KELSEY, Lafayette Coll. **Possible Influence of Point Source (Industry) and Nonpoint Source (Agricultural) Land Use Activity on Water Quality of the Bushkill Creek in Northampton County.** ACD: May 1990.

D. M. HOSKINS, Pa. Geol. Survey, WILLIAM GAST, Pa. Dept. of Environ. Resources, Bur. of Water Resources Mgmt., and ERIC ANDERSON, U. S. Geol. Survey. **Stream Map of Pennsylvania.** The 1965 "Higbee" stream map of Pennsylvania, long out of print and out of date, is being replaced by an up-to-date version based on digital data from the U. S. Geological Survey 1:100,000-scale topographic maps. This is a pilot project designed to learn how to use digital data organized by quadrangle at state map scale. ACD: 1991.

R. A. SLOTO, U.S. Geol. Survey. **Geohydrology and Groundwater Quality of Chester County.** A comprehensive evaluation of the groundwater resources and a statistical evaluation of inorganic, organic, and radiochemical groundwater data. ACD: Sept. 1990.

A. M. STERNAGLE, Pa. Dept. of Transportation. **Short- and Long-Term Effects on Groundwater Supplies Due to Construction Practices.** A study of water problems attributed to blasting and slope cutting shows that turbidity, total-solids ratios, and static water levels may fluctuate. Both shallow- and deep-well monitoring exhibit highly variable rates. ACD: 1992.

K. E. WHITE and R. A. SLOTO, U.S. Geol. Survey. **Base-Flow Recurrence Intervals for Selected Pennsylvania Streams.** This report will provide base-flow recurrence intervals determined by computer program using fixed-interval and local-minimum hydrograph-separation techniques. A discussion of physical factors affecting base flow is included. ACD: June 1990.

D. R. WILLIAMS, U.S. Geol. Survey, and T. A. McELROY, Pa. Geol. Survey. **Geology and Water Resources of Indiana County.** Field work has been completed. Two-, 4-, 24-, and 72-hour pump tests were conducted at the Plumville well nest. All field data have been entered into computer data bases. The geologic map has been compiled, and a basic-data report has been completed. ACD: 1990.

DAWNA YANNACCI, Pa. Geol. Survey, and DANIEL HIPPE and DENNIS LOW, U.S. Geol. Survey. **Aquifer Characteristics of the Rocks of Pennsylvania.** A comprehensive summary of the hydrogeologic characteristics of individual formations and regional systems will be developed using available data. The study will be conducted in three parts, the first covering southeastern Pennsylvania. ACD: Aug. 1990 (first part).

Igneous and Metamorphic Petrology

JOSEPH HULL, Uppsala Univ., Sweden, BOB KOTO, L. E. S. I., and JOHN PUFFER, Rutgers Univ. at Newark. **Ordovician Orogenic Alkaline Magmatism in the North-Central Appalachians.** We are studying alkaline basaltic dikes of the Taconic foreland, intruded late in the orogenic history (Group Y magmatism). Current work involves radiometric dating. ACD: 1991.

M. T. MANGAN, U. S. Geol. Survey, BRUCE MARSH, Johns Hopkins Univ., and A. J. FROELICH AND D. GOTTFRIED, U. S. Geol. Survey. **Flow Differentiation in York Haven Diabase Sheet, South-Central Pennsylvania** [York and Lancaster Cos.]. ACD: Aug. 1990.

D. W. VALENTINO, Pa. Geol. Survey. **Metamorphism and Structures of the Tucquan Antiform** [Lancaster Co.]. A detailed metamorphic and microstructural study across the Tucquan antiform has been completed. Syndeformational metamorphism is characterized by an episode of greenschist facies retrogression. ACD: 1990.

Mineralogy

J. H. DOOLEY, N. J. Geol. Survey, and J. S. DELANEY, Rutgers Univ. at New Brunswick. **An Exceptional Monazite Specimen in the Basal Hardyston Formation from Morgan Hill, Pennsylvania** [I–78 roadcut]. Scanning electron microscopy/energy dispersive X-ray spectroscopy examination of a 36-mm-diameter euhedral specimen of monazite ($(Ce,La,Y,Th)PO_4$) reveals light rare-earth-element-rich (predominantly La, Ce, and Nd oxides) exsolution lamellae of cerianite ($(Ce,Th)O_2$) and xenotime (YPO_4). Other mineral inclusions in the monazite specimen include thorite ($ThSiO_4$), thorianite (ThO_2), pyrite (FeS_2), and uraninite (UO_2). Metamict zones, which are highly degenerated by radioisotope decay, consist of thorium- and uranium-rich phases. ACD: Completed.

Paleontology

J. F. TAYLOR, Indiana Univ. of Pa., and J. D. LOCH, Univ. of Missouri. **Franconian (Middle Upper Cambrian) Trilobite Faunas in the Central Appalachians** [south-central Pa. and adjacent Md., W. Va., and northern Va.]. Faunas in the Ore Hill Limestone (Gatesburg Formation) are under study to update the taxonomy, refine correlations, and collect lithologic and range data critical to evaluation of hypotheses regarding Late Cambrian mass extinctions. ACD: Ongoing.

ALFRED TRAVERSE AND CARMEN MOY, Pa. State Univ. **Palynostratigraphy of Catskill Magnafacies Rocks of Pennsylvania** [central Pa., from N. Y. border to Md. border]. ACD: Ongoing.

P. D. ZELL and ROGER CUFFEY, Pa. State Univ. **Paleontology of the Lower Ordovician Nittany Dolomite in Central Pennsylvania.** Investigation of a diverse mollusc-dominated assemblage, with the intent of recognizing fossil communities of Tremadocian age. ACD: 1992.

Sedimentology

EDWARD COTTER and JOHN LINK, Bucknell Univ. **Genesis of Clinton Ironstones (Silurian), Central Pennsylvania.** ACD: Summer 1992.

A. E. GATES, Rutgers Univ. at Newark, and D. W. VALENTINO, Pa. Geol. Survey. **Evidence for Rift-Generated Deposits in the Peters**

Creek Formation: Precambrian/Cambrian(?) Age [Lancaster Co.]. QFL plots of quartzite compositions for the Peters Creek Formation indicate that the sedimentary provenance is a continental block, transitional to basement uplift. The quartzite compositions and numerous other features are consistent with rift generation. ACD: 1990.

M. J. PODNIESINSKI and BOBB CARSON, Lehigh Univ. **Sedimentary Petrology and Geochemistry of an Unroofing Event in the Taconic Clastic Wedge Source Terrane, Eastern Pennsylvania.** A study of the change in provenance in Silurian sedimentary deposits in eastern Pennsylvania and the tectonic implications of the unroofing of the southeastern source terrane. ACD: Oct. 1990.

DON WOODROW and ARTURO CORTES, Hobart and William Smith Colls. **Study of a Nearshore Sand Body (Late Devonian), Tioga and Hammond Dams, Tioga, Pennsylvania.** ACD: Spring 1991.

Stratigraphy

J. T. DUTRO, JR., and JOHN REPETSKI, U. S. Geol. Survey, J. F. TAYLOR, Indiana Univ. of Pa., BOB GANIS, Tethys, Inc., and DAVE HOPKINS, J. E. Baker Co. **Cambrian Shelf-Edge Stratigraphy, York Valley.** All formations in the West York quadrangle are Early or Middle Cambrian. The time-transgressive nature of the rock units between York and Lancaster Counties supports the model proposed by John Rodgers in 1968. An unconformity below the York County "Conestoga" is not indicated. ACD: 1991.

W. E. EDMUNDS, Consulting Geologist. **Lower Pennsylvanian Marine Invertebrate and Plant Fossil Zone, Fulton County.** A previously unrecognized Lower Pennsylvanian marine invertebrate and plant fossil zone occurs in the rocks equivalent to the Tumbling Run Member of the Pottsville Formation at least several hundred feet above the Wymps Gap marine zone. It may correlate with the Pocahontas Formation or lower New River Formation of southern West Virginia. ACD: 1991, unless expanded.

A. D. GLOVER, P. F. BUIS, C. H. DODGE, L. J. LENTZ, J. R. SHAULIS, and V. W. SKEMA, Pa. Geol. Survey. **TASIC (Temporarily Available Stratigraphic Information Collection).** A continuing program to collect stratigraphic data and coal samples for analysis from active coal and clay mines and from drill cores in north-central and western Pennsylvania. The project will provide data for future mapping and regional resource evaluation. ACD: Ongoing.

W. M. GOODMAN, C. E. BRETT, and S. T. LoDUCA, Univ. of Rochester. **Stratigraphic Dynamics of the Medial Silurian (Wenlockian), Northern Appalachian Basin** [Pa., Md., N. Y., and Ontario]. We have mapped disconformity-bounded sedimentary sequences in the upper Clinton (upper Rose Hill, Keefer, Rochester, basal McKenzie, and equivalent Lizard Creek). This summer we will work near Swatara to study the Clinton-Shawangunk facies transition area. ACD: Fall 1990.

J. D. INNERS, Pa. Geol. Survey, W. E. EDMUNDS, Consulting Geologist, and L. J. LENTZ, Pa. Geol. Survey. **Mauch Chunk/Pottsville Stratigraphy and the Mid-Carboniferous Boundary in the North Half of the Anthracite Region** [northeastern Schuylkill Co., northwestern Carbon Co., and Luzerne Co.]. Objective is to determine the nature and areal extent of the basal Pottsville disconformity that is evident in the Northern Anthracite field and the northern part of the Eastern Middle field and to interpret the sedimentary environments of the upper Mauch Chunk strata beneath the disconformity. ACD: March 1991.

LESLIE OLINGER and A. C. DONALDSON, W. Va. Univ. **The Stratigraphy and Sedimentology of the Acadian Clastic Wedge in Southwestern Pennsylvania.** Master's thesis will include correlation of well logs into cross sections of the Upper Devonian-Lower Mississippian stratigraphy of southwestern Pennsylvania. Isopach maps of the correlated sand bodies will be used to determine shoreline position and strike/dip trends. ACD: Dec. 1990.

B. N. SHAFFER, Cyprus Emerald Resources Corp. and W. Va. Univ. **The Stratigraphy of the Allegheny and Conemaugh Groups and the Economic Geology of the Upper Freeport Coal in Eastern Greene County.** A compilation of the relatively unknown stratigraphy of the Allegheny and Conemaugh Groups, as well as a quantitative survey of the economic geology of the Upper Freeport coal in eastern Greene County. ACD: Feb. 1991.

R. C. SMITH, II, and S. W. BERKHEISER, JR., Pa. Geol. Survey, and J. H. WAY, Lock Haven Univ. **Lower Devonian and Other Bentonites and Ash Beds** [Va. to Quebec]. Bald Hill Bentonite Beds A, B, and C have now been correlated from Monterey, Virginia, to Cherry Valley, New York. These as well as the Upper Ordovician bentonites and Tioga ash beds are associated with the drowning of carbonate platforms by major marine transgressions. ACD: Ongoing.

J. F. TAYLOR, Indiana Univ of Pa., and N. J. DURIKA, J. T. DUTRO, and J. E. REPETSKI, U. S. Geol. Survey. **Cambrian-Ordovician Bio-**

stratigraphy of the Conestoga Valley. Mildly deformed shelf-marginal carbonates in the Kinzers and Ledger Formations near York, Pennsylvania, are being sampled for trilobites and phosphatic microfossils to establish a standard for correlation of Lower Cambrian strata in the Appalachians. ACD: Summer 1991 (first phase).

J. F. TAYLOR AND K. A. RITTLE, Indiana Univ. of Pa., and J. E. REPETSKI, U. S. Geol. Survey. **Upper Cambrian and Lower Ordovician Biostratigraphy in the Central Appalachians** [Nittany Arch and Great Valley areas (Pa., N. J., Md., W. Va., and Va.) and Frederick Valley, Md.]. The Stonehenge Limestone and the units above and below it are being systematically sampled to establish a trilobite- and conodont-based biostratigraphy for precise correlation with Trempealeauan and Ibexian strata elsewhere in North America. ACD: Ongoing.

Structural Geology

R. T. FAILL, Pa. Geol. Survey. **Tectonic Map of Pennsylvania.** Map will show locations and names of anticlines, synclines, anticlinoria, structural fronts, thrust, normal, transcurrent, and other faults; basement contours; contours on top of the Onondaga Formation; earthquake epicenters; radiometric dates; nappes and terranes; metamorphic isograds; and other sundry tectonic features. ACD: Nov. 1990.

M. B. GRAY, Univ. of Rochester. **Tectonothermal History of the Southern Anthracite Region.** ACD: 1991.

H. A. POHN, U. S. Geol. Survey, and J. L. COLEMAN, JR., Amoco. **Appalachian Structures** [central Pa.]. Radar data, seismic-reflection profiles, and field studies have shown the presence of a lateral ramp in central Pennsylvania. A basement connection is suspected because of seismicity under the ramp. ACD: Completed.

SAM ROOT, Coll. of Wooster. **Basement Tectonics of the Transylvania Fracture Zone, Pennsylvania and Ohio.** Study of Paleozoic reactivation of a Precambrian basement fracture.

R. W. VALENTINO, Temple Univ., D. W. VALENTINO, Pa. Geol. Survey, and B. J. LAMPORT, Elizabeth Seton Coll. **Post-Taconian Structures of the Philadelphia Terrane.** The Springfield ductile thrust and the Rosemont and Crum Creek conjugate shear zones have the same post-Taconian metamorphic history, indicative of cogenetic development. A transpressional deformation model has been proposed for these structures. ACD: 1990.

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compiled by Caron O'Neil
Pennsylvania Geological Survey

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White, T. S., Davis, A., and **Morrison, J. L.,** 1989, The distribution and emplacement of pyrite in the Clarion coal of western Pennsylvania [abs.]. Geological Society of America Abstracts with Programs, v. 21, no. 6, p. A163.

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Engineering Geology

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Environmental Geology

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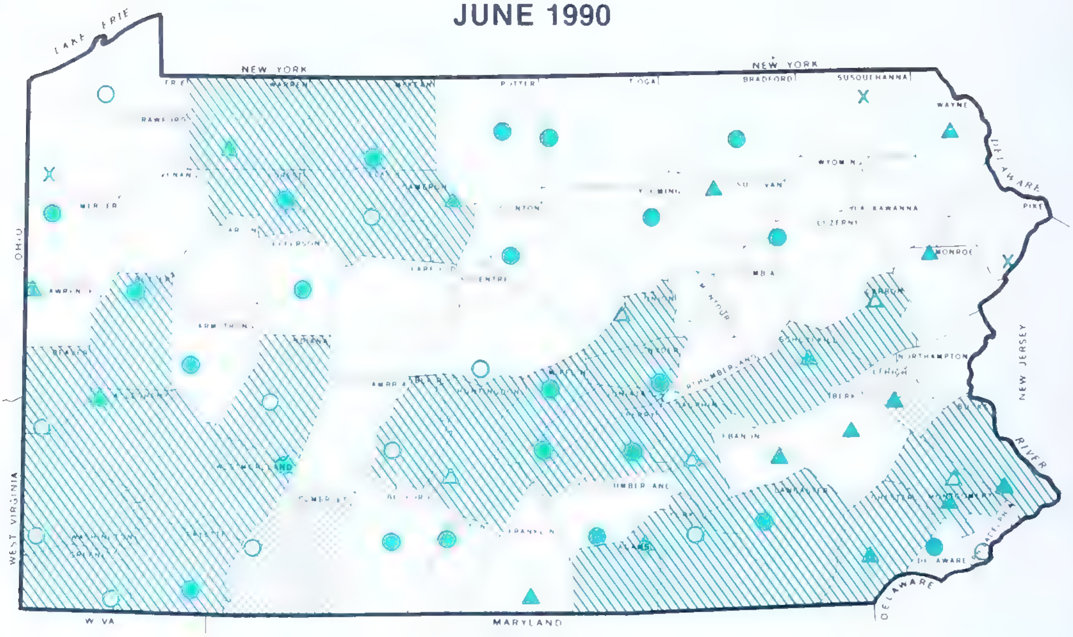

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PENNSYLVANIA GEOLOGY

PENNSYLVANIA GEOLOGICAL SURVEY VOL. 21/5

COMMONWEALTH OF PENNSYLVANIA
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ON THE COVER: Wolf Rocks on the Appalachian Trail, described by J. Peter Wilshusen on page 13 of the popular book *Geology of the Appalachian Trail in Pennsylvania*. "Pete," who retires this month after 25 years of state service, described this quartzite outcrop as Shawangunk Formation at a site that marks the southernmost limit of continental glaciation along the Trail.

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Pete Wilshusen Retires

In an old newsletter about the Appalachian Trail in Dauphin County are these lines from Richard Hovey's poem "Spring":

> . . . I will up and get me away where the hawk is wheeling,
> Lone and high,
> And the slow clouds go by . . .

It was with this spirit that John Peter Wilshusen, "Pete" to his friends and colleagues, proposed to the Pennsylvania Geological Survey in 1979 that we should prepare and publish a guide to the *Geology of the Appalachian Trail*. Published in 1983, this book has brought pleasure and knowledge to countless hikers on Pennsylvania's part of the Trail. It is but one of many well-known products of a quarter century of public service, now officially ended with Pete's retirement. The Appalachian Trail guide was a labor of love for Pete, for he had long been associated with the Trail as he hiked on it, and in his quiet and selfless style, volunteered his time to maintain the Trail for others.

Throughout two and a half decades, Pete has served the Commonwealth in many capacities. Working hard and giving of his own time through lengthy field days, Pete produced many other well-known publications, such as the popular Educational Series 9, *Geologic Hazards in Pennsylvania*, and several Environmental Geology Reports, including EG 6, *Environmental Geology of the Greater York Area, York County, Pennsylvania*. Pete was author of Park Guide 1, *Trough Creek State Park*, the first guide issued in the Survey's Pennsylvania Trail of Geology series.

During 15 years as a member of the Environmental Geology Division of the Survey and as its Chief since 1985, Pete daily responded to many citizens' requests for information and assistance. He patiently explained complex geological and hydrogeological ideas to homeowners, well drillers, engineers, and elected officials so that he unfailingly aided them in resolving problems relating to Pennsylvania's complex geology. Prior to this, Pete served as Chief of the Editing Section and was instrumental in saving priceless manuscripts and drafted copy that became waterlogged when the Survey's offices were destroyed in the 1972 Hurricane Agnes flood.

The Commonwealth of Pennsylvania, his colleagues, and Pennsylvanians have all benefited from Pete's many endeavors. Pete plans to continue geological writing and research on a volunteer basis for the Pennsylvania Geological Survey. Whether it is at his farm in New Hampshire, or at a familiar desk writing about the geology to be seen in Pennsylvania's state parks, we wish Pete fulfillment and the opportunity to get "away where the hawk is wheeling."

Donald M. Hoskins

Donald M. Hoskins
State Geologist

IN MEMORIAM

Marchant Nissley Shaffner
(1897–1990)

The recent passing of M. N. Shaffner at the age of 92 has deprived the Pennsylvania geological community of one of its most memorable personalities. Known universally as "Mike," he was born in Harrisburg, Pennsylvania, a few blocks from the site of the present Governor's Residence, on October 21, 1897. He attended the city schools and remained a lifelong resident of the Harrisburg area.

Mike was employed briefly by the Pennsylvania Geological Survey in 1922 and 1923 and rejoined the Survey in December 1927, where his talents where employed for the next 35 years. He was that rarest of geologists, one who learned the profession on the job from independent study and close association as an assistant to others. It is clear from his later publications that Mike received a great deal of his instruction from the eminent coal specialist and State Geologist of the Fourth Geological Survey of Pennsylvania, George H. Ashley. Recognizing a latent talent, Dr. Ashley arranged for Mike to receive a complete set of lecture notes from the famous professor and field geologist of the Second Pennsylvania Geological Survey, J. J. Stevenson.

Mike was first employed as a draftsman and clerk, and, in 1930, was promoted to geological assistant. In the course of the next several years, while serving as office and field assistant to many of the staff geologists, he acquired an understanding of the basic geology of Pennsylvania and the principles of field mapping. He became so conversant with the geology of the coal fields of western Pennsylvania that in 1937 he was assigned the mapping of the Smicksburg 15-minute quadrangle in Jefferson, Indiana, and Armstrong Counties.

Although he was frequently diverted to strategic resource studies during World War II and to other projects, the Smicksburg atlas was completed in 1947. Mike was next assigned mapping investigations of the western part of the Allegheny Mountains, covering parts of Fayette, Somerset, Westmoreland, Indiana, and Cambria Counties. Field work in this area continued until 1960 and resulted in two major publications: the New Florence atlas in 1958 and the Donegal atlas in 1963. Mike was a meticulous observer of the highly variable geology in the areas where he worked, and his lengthy reports are thorough and carefully crafted.

Mike Shaffner in the field near Coudersport, Pennsylvania, August 1931. Photograph by Bradford Willard.

Mike closed his professional career in December 1962, when he retired, having seen the Fourth Pennsylvania Geological Survey through most of its first four decades. A few years later, Mike and his wife, the late Hattie Shaffner, moved from Camp Hill, Pennsylvania, to their retirement home in Stony Creek valley, north of Harrisburg.

Gregarious and personable, Mike had a wide circle of friends and was at ease with people from all walks of life. In the course of his work, he dealt with miners and industry executives with equal facility. During the many seasons of field work in the Allegheny Mountains, Mike came to consider Ligonier, Pennsylvania, as his second home. For many years thereafter, it was possible to find people from that area who remembered Mike. An inveterate humorist and spinner of yarns, he was a veritable storehouse of anecdotes about his years with the Pennsylvania Geological Survey. As often as not, Mike would be the butt of his own stories. When Mike died on June 7, 1990, Pennsylvania geologists lost a colorful and vital friend, as well as the last link to the early years of the present Pennsylvania Geological Survey.

by William E. Edmunds

BRADYS BEND CORPORATION
Creating Value out of Thin Air

by S. W. Berkheiser, Jr., and R. C. Smith, II
Pennsylvania Geological Survey

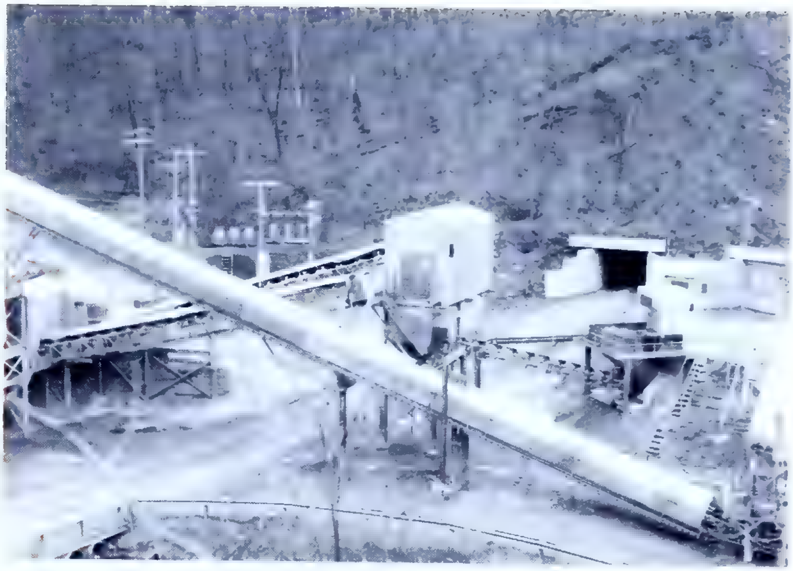
Symbiosis is the intimate association of two dissimilar organisms in a mutually beneficial relationship. At Bradys Bend Corporation in Armstrong County, underground limestone mining has created two dissimilar commodities that share a symbiotic relationship: aggregate and "space." The beneficial relationship is that mining creates secure storage space, and the revenue from renting the space makes mining possible. As an added bonus, the environmental impact of surface mining is avoided.

As is the case with many of Pennsylvania's mining operations, Bradys Bend Corporation is steeped in tradition and has roots extending back to the nineteenth century. The original quarry workings were initiated by a Mr. Frazier to produce lime and fluxstone for the local iron industry in the 1890's. By 1911, when Pennsylvania was producing 25 percent of the nation's lime, there were 76 active lime producers in Armstrong County (Hice, 1911). The grandfather of Ken Vogt, the current superintendent at Bradys Bend, worked for Mr. Frazier as a blacksmith and napper (the napper assured that all hand-won quarry stone could pass through a 22-inch-diameter steel hoop). Around the turn of the century, the Pittsburgh Limestone Company, a subsidiary of the United States Steel Corporation, purchased the operation and began to develop the area into an approximately 2,000 acre resource with three extensive underground adit mines. Ken's father worked his way up to assistant mine foreman for the operation. U.S. Steel operated these mines for 57 years, producing a high-calcium fluxstone for its furnaces. Today, Ken's son is in charge of the storage aspect of this unique enterprise.

LOCATION AND SETTING. The plant and main storage entrance of Bradys Bend Corporation (Figure 1) are located about one-half mile west of Bradys Bend in northwestern Armstrong County, on the west side of Cove Run, a small tributary to Sugar Creek. This is about 65 miles north of Pittsburgh and about 1 mile west of Pool 9 on the Allegheny River.

Here in the Appalachian Plateaus physiographic province, the Vanport Limestone, formerly termed the Ferriferous limestone (Platt, 1880), crops out in nearly flat lying beds along stream drainages. The Lower Kittanning coal typically occurs about 20 feet above this marine limestone, and the Clarion coal typically is present about 40

Figure 1. Main service entrance (adit) to the No. 3 mine of Bradys Bend Corporation.



feet beneath the mine floor. The Buhrstone iron ore (sometimes cherty—accounting for the "buhr" in buhrstone), extensively mined in the last part of the nineteenth century for a siderite iron ore bed less than 2 feet thick, locally rests on top of this limestone but was not observed at Bradys Bend. Similarly, a thinner ore bed can occur beneath this limestone (Platt, 1880).

MINING. "Ore" consists of the Vanport Limestone (Allegheny Group), which locally can reach a maximum thickness of about 20 feet, and a total of 2,300 motor homes, recreational vehicles, boats, and vintage automobiles (Figure 2).

The Vanport Limestone is a dark-gray to brownish-gray carbonate mudstone to grainstone containing common fossil fragments of brachiopods and crinoids. Typically, the basal 11 to 12 feet of limestone was extracted, leaving 28 to 32 inches of carbonate overhead to support the roof. The roof follows a well-developed stylolitic plane (a suture-like interpenetration along which insoluble constituents have accumulated, presumably caused by dissolution). Another conspicuous stylolite marker occurs throughout the mine about 4 feet above the floor. Calcium carbonate content is high, generally between 92 and 96 percent.

Shortly after acquiring the property, U.S. Steel started conventional underground mining, generally as alternating 30-foot rooms with 30-foot pillars. This, of course, provided an approximately 50 percent extraction ratio. This is quite a contrast to other Vanport Limestone strip-mining operations in the Appalachian Plateaus province, where up to 150 feet of overburden is removed by earth movers and draglines to yield a nearly 100 percent extraction ratio (Pennsylvania

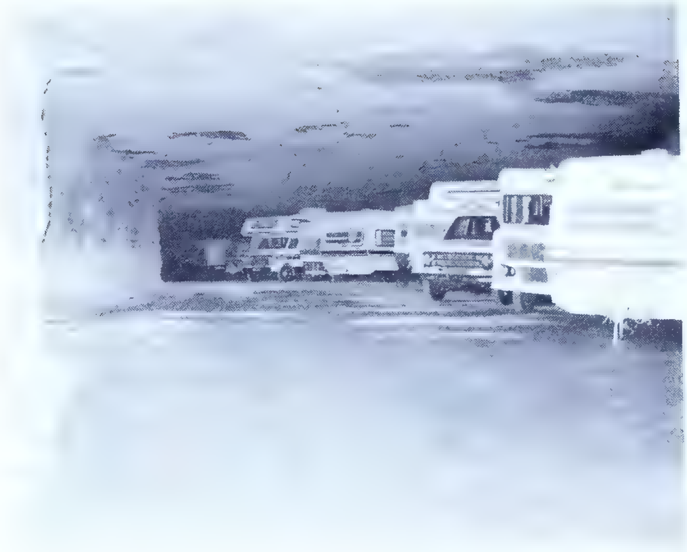


Figure 2. Recreational vehicles in the prepared 70-acre underground facility.

Geological Survey, 1986). It is reported that U.S. Steel pioneered a blasting technique here known as horizontal "V" drilling. An estimated 70,000,000 tons of virgin high-calcium limestone remained when U.S. Steel sold the property in 1964.

Bradys Bend Corporation produces less than 100,000 tons of limestone per year, mostly for the construction industry. About 5,000 tons per year of this is pulverized in a cage mill for agricultural limestone. Most production comes from trimming pillars in the No. 3 mine. Three 15-ton customized side-load haul trucks and one rubber-tired high lift keep the roller and hammer mills supplied with raw materials.

STORAGE. Over 30 million square feet of underground space is potentially available for many uses, including light industry and manufacturing. Ken and his son have developed a virtual underground city complete with model offices and restrooms. About 70 acres has been developed for storage, and nearly all of this is presently being utilized. Another 30 acres is under development. Converting the mine into secure storage or office space involves installing lighting, partitions, and subfloor drainage. Although natural, year-round temperatures range between 50° and 55°F, approximately 350 units of the 2,300 spaces available are heated to 68°F and kept at an average relative humidity of 55 percent. Most of the storage areas have a minimum clearance of 10.5 feet, but some 16-foot-high sites were prepared by excavating the floor deeper. The advantages of such underground storage include a constant year-round temperature, low maintenance, safety and security, fire resistance, and adaptability (custom-designed facilities are available).

Bradys Bend Corporation has shown resourcefulness and creativity in providing employment and useful services for the people of Armstrong County by using a symbiotic approach to free enterprise. Ken

Vogt's emphasis on safety in the operations is highly apparent, as demonstrated by his efforts as a founder and continuing member of Pennsylvania's Mine Rescue Team.

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1:100,000 Metric Topographic Map Series Complete for Pennsylvania

In April 1984, a new series of topographic maps at a scale of 1:100,000 was announced in *Pennsylvania Geology* (volume 15, number 2, page 7). With the recent publication of the topographic edition of the Ashtabula (Ohio-Pennsylvania) quadrangle, the series is now complete.

These intermediate-scale maps are useful as regional base maps because each covers approximately 1,836 square miles (the area covered by thirty-two 7.5-minute topographic maps). To obtain complete coverage for Pennsylvania at the 1:100,000 scale requires 35 of the new maps. Contours and spot elevations on these maps are in metric units. One centimeter on the map equals 1 kilometer in distance scale, or about 0.6 mile on the ground. One inch on the map equals about 1.6 ground miles.

The maps are multicolored and show political boundaries, highways, man-made structures, cultural features, and topographic contours. The contour interval is 20 meters. Each map covers 1 degree of longitude and 30 minutes of latitude.

The 1:100,000-scale maps are available for $4.00 each from the U.S. Geological Survey, Map Distribution, Box 25286, Federal Center, Denver, CO 80225. A $1.00 handling charge should be included for orders of less than $10.00. Prepayment is required, and checks should be made payable to *U.S.G.S.* For more information, contact the Pennsylvania Geological Survey library, telephone 717-783-8077, or the Earth Science Information Center (ESIC), U.S. Geological Survey, telephone 1-800-USA-MAPS.

JOHN F. CARLL

Pennsylvania's Prophet of the Oil Fields

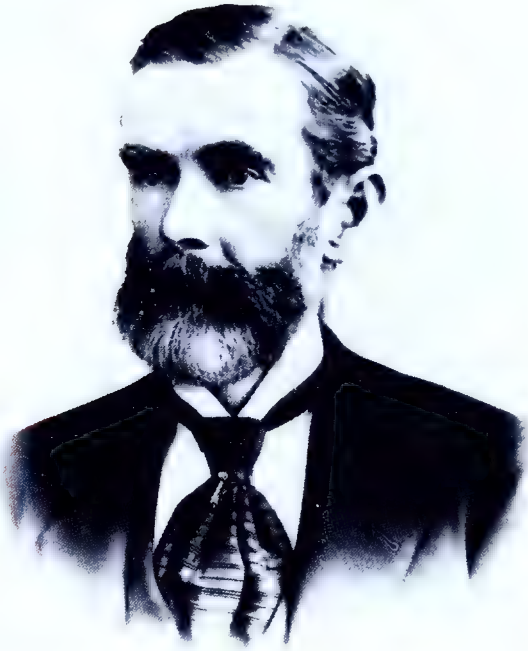
by John A. Harper
Pennsylvania Geological Survey

In order to do their jobs effectively, petroleum geologists need to understand the rocks that have been penetrated in drilling a well—what the rocks look like, how deep and how thick they are, what fossils, minerals, and other constituents they contain, and how they correlate with the rocks found in other wells. To this end, many geologists spend a considerable amount of time looking at drill cuttings and making or studying strip logs. A strip log is a graphic representation of the rocks in the well combined with a description of the lithology, mineralogy, fossils, and any other characteristics of note printed alongside. Although strip logs are an essential part of their business, very few petroleum geologists are aware that the strip log was invented in the oil fields of Venango County, Pennsylvania, in the 1870's by John F. Carll (Lytle, 1957) (Figure 1). Figure 2 illustrates the earliest known surviving example of one of Carll's strip logs.

But the strip log was only one small contribution to the geology of oil and gas made by this remarkable man. "It is not too much to say that, however much was previously guessed at, or suspected to be true, the Geology of Petroleum has been virtually created by him . . ." (Lesley, in Carll, 1883, p. xii). Such high praise from a person of the caliber and esteem of J. Peter Lesley, Director of the Second Geological Survey of Pennsylvania, is noteworthy indeed. As State Geologist of the then most productive oil state in the world, Lesley was regarded as one of the more knowledgeable and influential men of science at the time. Carll, an assistant state geologist for the Second Survey, was charged with the task of investigating the geology of oil and natural gas in the producing areas of Pennsylvania. He was also one of the first geologists to make a concerted effort to compile, organize, and interpret the numerous available data on the geology of oil and gas reservoirs.

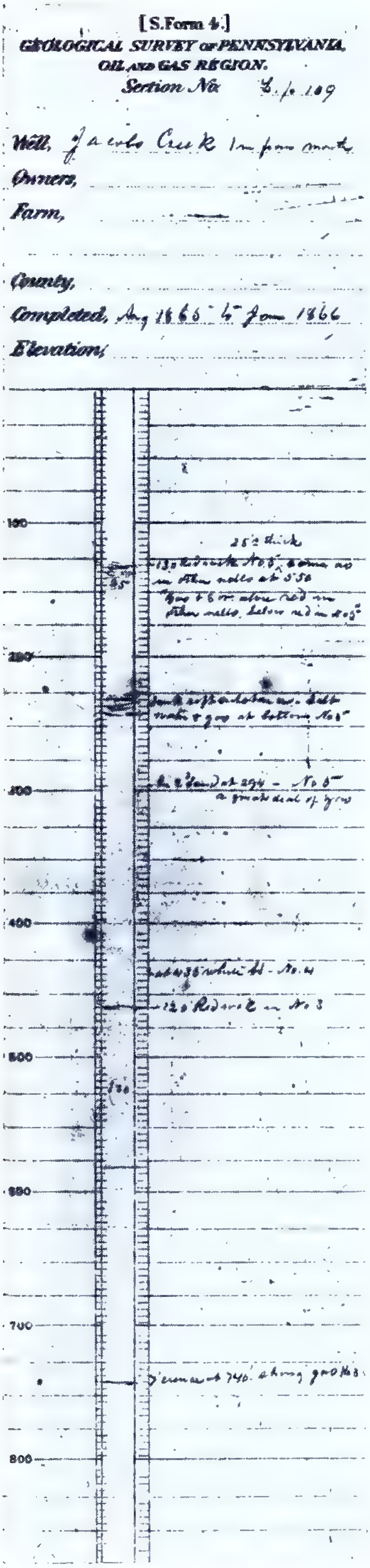
John Franklin Carll was born on a farm in what is now Brooklyn, New York, on May 7, 1828. Although he received a basic education at Union Hill Academy on Long Island, and studied some civil engineering, he was essentially self taught. His background was extensive, however, because he had a great deal of experience working as a farmer, newspaper editor, surveyor, civil engineer, and wire manufacturer before he finally moved to Venango County, Pennsylvania, in 1864

Figure 1. John F. Carll (1828–1904), Pennsylvania's pioneering petroleum geologist and engineer.



to try his luck in the oil business (Lytle, 1957). Over the next nine years he followed the oil industry, becoming familiar with drilling and production methods, making careful observations of the different rock layers penetrated in drilling, and collecting records on numerous wells. Because of his extensive knowledge of the various subsurface formations in the areas around Oil City and his general habit of close observation, he soon received widespread acknowledgement as a geologist. Local oil men eagerly sought his advice on where and to what depth they should drill. He even invented and patented some oil-field equipment during this period (Coberly, 1961).

When the Second Geological Survey of Pennsylvania was established in 1874 under the direction of Lesley, John Carll was appointed assistant geologist in charge of the oil districts of western Pennsylvania. Lesley, who had done some petroleum consulting work in 1865 (Owen, 1975), was familiar with the industry and the geological problems requiring attention in the oil fields. He understood that the oil "boom" occurring in western Pennsylvania afforded a great opportunity to study the subsurface geology of the area, something that could not be done previously, as well as to determine the nature of the petroleum resources of Pennsylvania. Carll's engineering background, his practical oil field experience, and his insistence on acquiring large quantities of reliable data stood him in good stead for his new position as the Survey's expert on subsurface geology and the petroleum industry.


[S.Form 4.]
GEOLOGICAL SURVEY OF PENNSYLVANIA.
OIL AND GAS REGION.
Section No. L. p. 109

Well, Jacobs Creek 1 m from mouth
Owners,
Farm,
County,
Completed, Aug 1865 - 4 Jan 1866
Elevation,

100
200
300
400
500
600
700
800
25' thick
a great deal of gas

Carll's first Survey report was published in 1875, only one year after his appointment. Before joining the Survey, he had already demonstrated that the oil sandstones of the Oil City area persisted throughout most of the region, and had made great strides in defining the stratigraphic and lithologic characters of the "Venango Oil Sand Group" (Venango Formation of present usage). Carll's first volume was only a preliminary report, but it contained an enormous amount of information, most of which he and others had collected over the previous 10 years. It contained logs and surveyed elevations of numerous wells, elevations relative to sea level for the major reservoir sandstones, and discussions on many aspects of the chemistry, geology, and engineering of petroleum. Carll covered, among other topics, the origin of petroleum, the correlation of reservoir sandstones, and the importance of subsurface geologic structure in the oil fields, presenting the first structure maps of subsurface formations.

Carll's second report was a compendium of well logs for 1,654 wells throughout northwestern Pennsylvania. In addition, it contained precisely surveyed elevations along the railroads of that area.

His third report, published in 1880, is considered by many to be his magnum opus and one of the most remarkable books on early petroleum geology ever written. It covers the geology of the Pennsylvania oil regions of Warren, McKean, Venango, Clarion, and Butler Counties, and includes both a survey of the Upper

Figure 2. The earliest known example of a strip log, constructed by John Carll around 1877.

Devonian Garland and Panama Conglomerates and a discussion of the pre- and post-glacial drainage of Erie County. The volume also contains descriptions and illustrations of drilling rigs and tools and discussions of drilling and production methods.

At a very early stage in his career in the oil fields, Carll recognized the necessity of keeping accurate driller's records, and he spent considerable time and energy trying to convince the oil producers of this during his tenure with the Survey. One chapter in the 1875 report and two in the 1880 report were devoted in part to preaching about well records, attempting to show their value beyond mere record keeping.

> It is said that about four thousand well-shafts were sunk in the oil fields of Penna. and New York during the one year of 1877. . . . What a broad field for geological study would their records have afforded if they had been properly kept and were now accessible to us. But unfortunately for the interests of the survey, the oil producer is drilling solely to benefit himself and cares very little for the advancement of science or the financial welfare of those who may drill after him. Of this large number of wells, probably there has not been preserved a special record of *one in a hundred*, and but few of those that have been preserved can be obtained in a shape to be of any use to the Survey [Carll, 1880, p. 165–166].

His persistence paid off in part. Many of the records he collected for oil and gas wells drilled in western Pennsylvania are still available and can be used by geologists looking for precise subsurface information in areas of limited control.

Some of Carll's more important ideas and initiatives have been substantiated and used in the industry for years. He documented the importance of gas in the movement of oil through a reservoir, a fact that was "discovered" in 1912 (Johnson, 1912; actually, Lesley first proposed a form of this idea in 1865 in a report to the U.S. Commissioner of Agriculture). He postulated that flooding an oil reservoir with water would stimulate production. Waterflooding is now a standard industry practice used extensively the world over, but it only began to be used in the 1920's, more than 15 years after his death. He documented a method of collecting drill cuttings and declared that they could be used to supplement, and even improve upon, the drillers' records. And his hypotheses on the shapes and geological origins of the reservoir sandstones of the oil regions have been substantiated by more recent geological investigations (for example, Dickey and others, 1943).

Carll gave the petroleum industry seven reports packed with raw data and the geological and engineering interpretations based on those data, all the result of conscientious investigation and scientific description made throughout western Pennsylvania. He took extreme care to insure the accuracy of his information, and made sure it was published as useful products suitable to the average oil man. But as so often happens with brilliant men of science, the petroleum industry ignored his pleas and most of his ideas. Even though he inaugurated many of the subsurface geological methods employed today, they came into general use only after a 40-year hiatus, ". . . and then by geologists who either had never heard of him and his work or chose to ignore him" (Owen, 1975, p. 106).

Carll resigned from the Survey in 1882, frustrated by what he considered a lack of understanding or interest in his ideas and methods. Even his former colleague, I. C. White, described him as "an old county surveyor with no imagination and unable to generalize on the data he collected" (quoted in DeGolyer, 1961, p. 29). This statement was patent nonsense, but it conveys the general feelings of the industry at the time. He had not discovered the simple method for finding great quantities of oil in undrilled areas that the industry was expecting from him, so they ignored him. His writings were largely unread and his pleas for better records unheeded. He returned to the Survey in 1885, but left again in 1888 to pursue a career in consulting geology. He died in Arkansas in 1904, largely forgotten by his fellow scientists and oil men.

Today, historians regard John Carll as a visionary, the man who almost single-handedly invented the sciences of petroleum geology and petroleum engineering. But, as so often happens, the prophet had no honor in his own country and in his own time.

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NEW PUBLICATIONS

MINERALS TODAY

A New Magazine About the Mining Industry—and More

- *The damage caused by last October's California earthquake may have been worsened by poor maintenance of the Bay Area's infrastructure, over 40 percent of all bridges in the nation should be repaired or replaced, and much of the interstate highway system needs repairs; yet during the past two decades public-works construction has declined by almost one third.*
- *New technologies, as well as everyday consumer products, depend on new materials—plastics, metals, ceramics, and combinations—that outperform traditional materials. The United States is the largest market for these materials, but is falling behind in their development and production.*

Those were among the topics discussed in the first issue of the magazine *Minerals Today*, published last January by the U.S. Bureau of Mines. This lively magazine offers feature articles that explore the ramifications of such matters on everyday life. Contributing authors examine proposed solutions and document the ways in which the mineral-producing industry is responding to the challenges of the 1990's.

As an example of the latter, the focus of the May issue is "Minerals in the Environmental Decade." The author of the

MINERALS
U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
MAY 1990
A 'Good Neighbor' Mine 20
Managing BLM's Mineral Wealth 24
Minerals in THE ENVIRONMENTAL DECADE

cover story, David S. Brown of the Bureau of Mines, presents arguments that are rarely heard elsewhere. For example,

> There should be a reasonableness in how to go about dealing with the natural environment. Public policy making should not be driven by fear or sensationalism . . . . Mankind should strive to balance realistic environmental goals with other competing societal goals, such as creating jobs, homes and hope for the millions in the world who are jobless, homeless, hungry and despairing. The environment cannot be considered in isolation from these kinds of human needs. Nor should a single-minded concentration on health risks of pollution blind decision makers to the health risks associated with joblessness, poverty and despair when economic growth is stymied . . . . Good stewardship means making decisions on the use of natural resources for the common good, as well as for resource preservation.

At first glance, this argument might be taken as an excuse to pollute and despoil the land, but he goes on to say,

> Economic growth provides the wherewithal to protect the environment. Only economically progressive nations can be good stewards of the natural environment. Where there is economic deprivation, environmentally devastating practices abound. Nations where economic growth is supported and innovation encouraged are the most willing and able to allocate significant resources to protect the environment. While developed nations may make impressive strides in cleaning up pollution within their respective borders, improving the global environment will require strong economic growth in the developing world.
>
> If strong economies and a healthy environment go hand-in-hand, then minerals are necessary for both to work together effectively. These minerals are the building blocks of . . . civilization. Everything in the world that cannot be grown is taken from the earth, processed, refined, and used to make things, including so-called advanced materials which have become the key to international competitiveness. These new mineral-based materials promise improved product performance, decreased energy consumption, longer service lives . . . .

To further illustrate this point, the author cites examples of pollution-reduction technologies that depend on the availability of specific minerals.

Two additional points that Brown makes are that locking away our nation's land without knowing its resource potential is not good stewardship, and that many mineral resources that could be obtained through recycling are lost. Regarding the latter, he points specifically to the federal government's "superfund" program that treats hazardous waste sites solely as a pollution problem and not as a potential resource. Brown asserts that many of the sites contain materials that could be recovered and reused. If this were done, materials availability would be increased, environmental goals would be realized, and, in some cases, a profit might be made at the same time.

In addition to thought-provoking feature articles, *Minerals Today* contains short news items pertaining to the mineral industries of the United States and the world, news of government activities that affect those industries, and announcements of other publications of the U.S. Bureau of Mines.

Minerals Today is published six times per year. A yearly subscription costs $13.00 ($16.25 outside the United States), and is available by writing to the Superintendent of Documents, Government Printing Office, Washington, DC 20402-9371.

—J. H. Barnes

ROADSIDE GEOLOGY OF PENNSYLVANIA

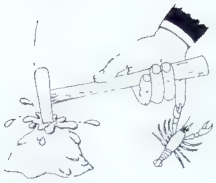
Readers of *Pennsylvania Geology* who are familiar with the state and have some general knowledge of geologic concepts might find a new book, **Roadside Geology of Pennsylvania**, by Bradford B. Van Diver, an interesting addition to their libraries. The most recent in a series of *Roadside Geology* books that now cover 15 states, this book can turn a journey down the highway into a journey through time as the geological features to be seen along many of the Commonwealth's major highways are pointed out and their possible origins are discussed. The book is organized by the major physiographic divisions of the state and, within each of those divisions, by highway. Maps show the route being discussed and the locations of some features that might be worth a closer look.

The primary emphasis of the book is on the Ridge and Valley province of central Pennsylvania and the Appalachian Plateaus province in the northern and western parts of the state. It is unfortunate that the author directs little attention toward the Piedmont Upland section of southeastern Pennsylvania, which includes the most populous part of the state and is one of the most geologically complex regions in Pennsylvania. Numerous errors also detract from an otherwise useful and worthwhile book.

Roadside Geology of Pennsylvania, a paperback book 352 pages in length, sells for $12.95. It is published by Mountain Press Publishing Company, P. O. Box 2399, Missoula, Montana 59806.

—J. H. Barnes

Geochips



Fishy Field Work

In 1988, Pete Wilshusen and other Survey staff used SCUBA to examine the bottom sediments off the Lake Erie shore. Pete commandeered a van and inflatable boat from the Pennsylvania Fish Commission. SCUBA tanks, wet suits, masks, flippers, and three staff scientists were all packed off to the balmy Erie shore. The group noticed that the van had large Fish Commission logos on each front door and wished that their association with the Geologic Survey were more obvious. This identity crisis, however, was soon lost in the excitement of following in the finsteps of Jacques Cousteau and Robert Ballard. The geologists thought only about the Calypso, the Titanic, and Ashtabula!

Yes, Ashtabula. One objective was to document how the huge jetty at Ashtabula, Ohio, interferes with the northeastward transport of sand to Pennsylvania's coast. Pete and crew navigated the harbor, dove all around the jetty, collected samples, made measurements, and returned safely to the dock.

While securing the gear, Pete noticed a large fishing boat tied to the dock. The fishermen on board were unloading a considerable catch of walleye—a popular game fish. Pete noticed the fishermen looking respectfully at him and his crew in their diving suits with all of their equipment. Always friendly, Pete walked over to the fishermen and admired their catch. "That's a nice catch of perch," Pete said, greeting his fellow mariners. Confusion clouded the fishermen's faces. They stared at Pete, then at their catch, then at the logo on the van. Bewildered, one of the fishermen replied, "Say what?" "That's a nice catch of perch," Pete repeated. "They're walleye!" the fisherman responded curtly; the rest shook their heads and directed their stares from Pete to the van and back to Pete. Pete then realized he had just misidentified the lake's prime game fish.

The group quietly returned to Pennsylvania. Pete is sure to this day he knows more about topography than tackle, more about petrology than Pisces, and more about water wells than walleyes. He's sure some Buckeye fishermen hope that Ohio Fish Commission scientists know more about fish than do their counterparts in the neighboring Keystone State.

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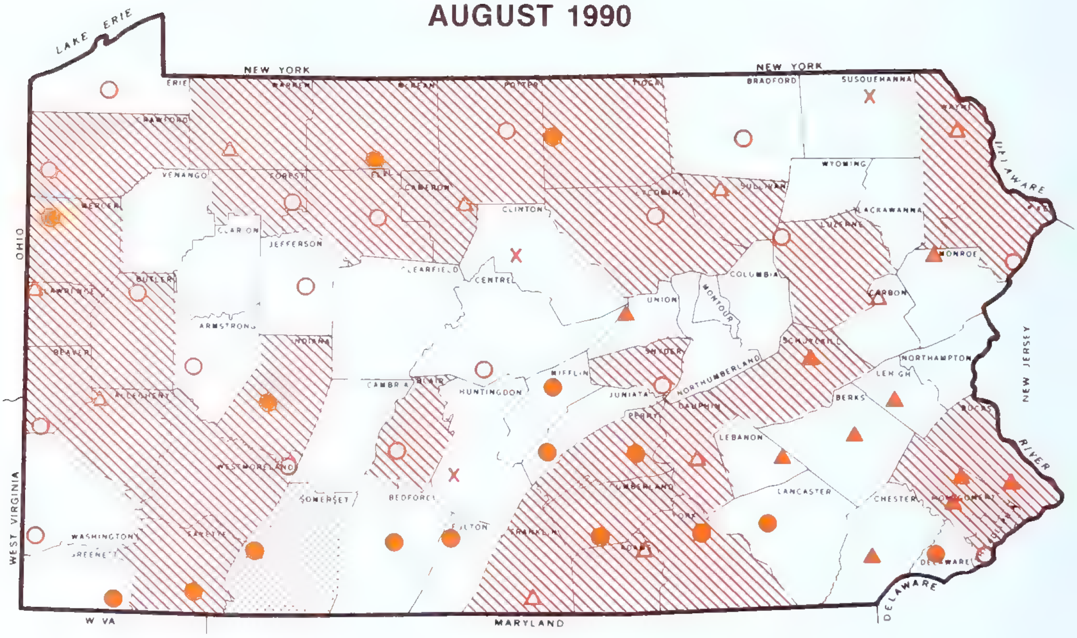

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△ Above last year
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PENNSYLVANIA GEOLOGICAL SURVEY
VOL. 21/6

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ON THE COVER: "The Sink," a large karst depression feature in the Devonian- and Silurian-age Keyser and Tonoloway Formations, located in the southwest quarter of the Montoursville South 7.5-minute quadrangle, Lycoming County. Observed in January 1986, this swallow hole had been filled with water and was later frozen over. The water then drained into a sinkhole, removing the support and causing the ice to collapse. The sinkhole is visible in the bottom center of the photograph. See *Pennsylvania Geology*, volume 3, number 4, for a related article, and page 7 of this issue for a different perspective of the same area. Photograph by W. E. Kochanov.

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Editors, Christine M. Dodge and Donald M. Hoskins.

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VOL. 21, NO. 6 **DECEMBER 1990**

FEB 15 1991

"Sunrise" Casts Light on Geologist Registration

The location of buildings, transportation routes, and utilities on steep slopes subject to landslides, on karst terrain subject to collapse, and in unstable areas subject to earth shaking is an ever-increasing state and national problem. Planning to avoid these hazards and mitigate their adverse effects is frequently the responsibility of geologists. Thus, there is a need for ensuring competency of these geologists.

In the past 20 years, 15 states have established programs requiring the registration of geologists who offer their services in investigating, explaining, and mitigating geologic conditions and hazards. The states' registration objectives are to ensure that professionals, who present themselves as experts, can meet certifiable minimum standards. Organizations such as the American Institute of Professional Geologists have suggested that self-regulation is the most desirable form of certification and regulation of professional practice.

Many states use a process called "sunrise" to review requests for the creation of new administrative agencies to prove that they are clearly needed for public protection. "Sunrise" is a natural consequence of the "sunset" process, in which existing governmental agencies are reviewed in order to remove any that are no longer needed.

Considerable controversy over the certification and regulation of geologists is evident amongst practitioners of the many subdisciplines of our science. In an attempt to overcome some of the controversy and answer the inevitable questions that will be asked during any "sunrise" or other legislative hearing process, several geological organizations have cooperated in drafting a model geologists' practice act. That model was among the topics discussed at the recent annual meeting of the Association of Engineering Geologists (AEG) in Pittsburgh, which featured a day-long colloquium focused on issues of geologist registration.

Geologists, engineers, state officials, legislators, and others interested in the registration of geologists will benefit by consulting the published report of the AEG meeting. The included papers on the philosophy of registration, ethical issues, and the experiences of other states will be extremely useful in any discussion of this topic. Indeed, the discussions on the

(continued on page 7)

STATE LIBRARY OF PENNSYLVANIA
DOCUMENTS SECTION

Healing a Wound in the Earth: DER's Kelayres Strip Mine Reclamation Project

by Jon D. Inners (DER, Bureau of Topographic and Geologic Survey), and David C. Hogeman, John R. Magula, and Lawrence Dobash (DER, Bureau of Abandoned Mine Reclamation)

> [Stripping] is extensively employed in the Hazleton district, where the visitor can see the hand of man, not leveling the rough places of earth, but rather, scooping out deep trenches . . . . A drive around Yorktown, Audenried, Honeybrook, and M'Adoo, shows to what extent these excavations have been and are still carried out. Everywhere deep cuttings [transform] a naturally rugged and barren mountain to a still more desolate region.
>
> Peter Roberts, *The Anthracite Coal Industry* (1901, p. 20)

INTRODUCTION. In late October 1989, at Kelayres in northeastern Schuylkill County, the Pennsylvania Department of Environmental Resources (DER) began the largest abandoned coal strip-mine reclamation job in its 16-year history. Before it is finished, nearly $9 million will have been spent to move 10,582,000 cubic yards of earth into a hole nearly 400 feet deep and 1.25 miles long. As one watches the earth movers (big by any other standard, but dwarfed by the yawning Kelayres mine) creep about on the rock and dirt slopes, several questions immediately come to mind. How did it come to scar the face of the land? How long has it existed? What is the geologic setting of the Kelayres pit? Why is it being filled? And, finally, where is the money coming from to pay for this enormous project? Through joint authorship of this article by a geologist (Inners), a hydrogeologist (Hogeman), a project inspector (Magula), and a civil engineer (Dobash), we will attempt to answer these four questions and, at the same time, provide some insight into the program for reclamation of abandoned-mine lands in Pennsylvania.

PHYSICAL SETTING AND GEOLOGY. The Kelayres strip mine is located about 4 miles south-southwest of Hazleton (Luzerne County) in the Eastern Middle Anthracite field (Figure 1). It occupies a narrow strip (750 to 1,000 feet wide) (Figures 2 and 3) bounded approximately by Interstate 81 on the west and Pa. Route 309 on the east. The village of Kelayres is situated along its southeastern edge, and the borough of McAdoo lies a little farther to the east. The general elevation of the broad upland—locally called "the Mountain"—into which the stripping was cut is about 1,700 feet.

The strip mine lies in the southwestern fork (Honey Brook syncline) of the Honey Brook-Jeansville basin, second largest of the numerous

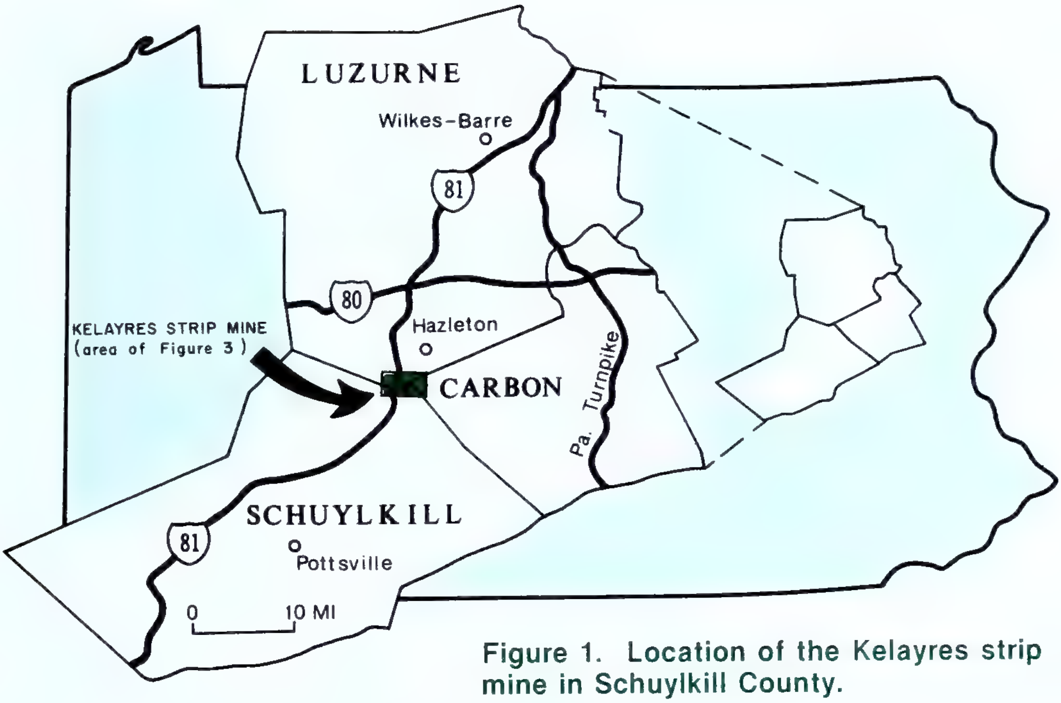

Figure 1. Location of the Kelayres strip mine in Schuylkill County.

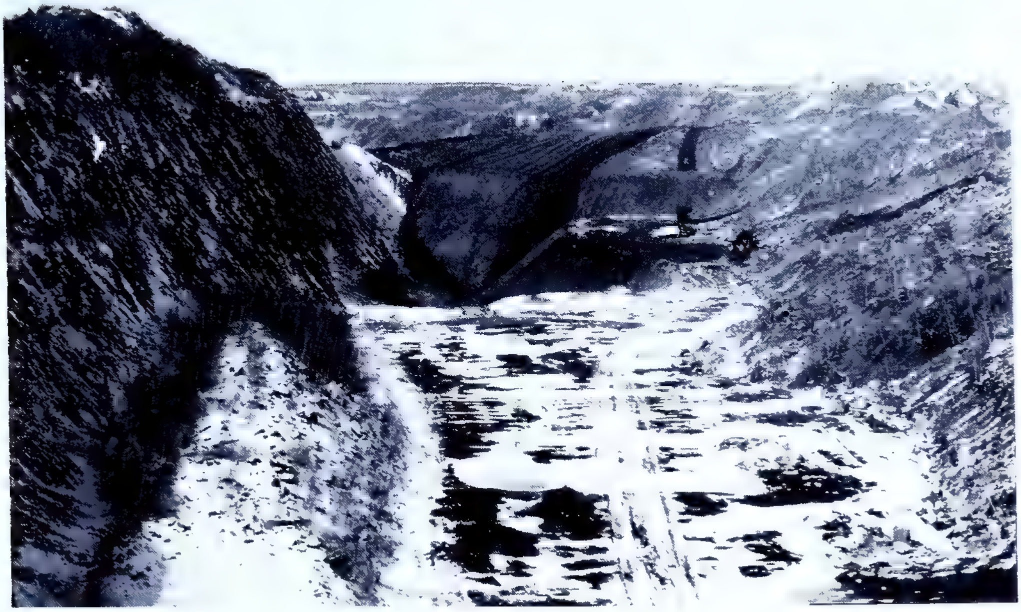

Figure 2. View of the Kelayres strip mine from near its eastern end on March 21, 1990, showing the seatrock of the Mammoth-Wharton coal bed on the south footwall dipping 50 degrees to the north. Two trucks in the middle distance give the scale.

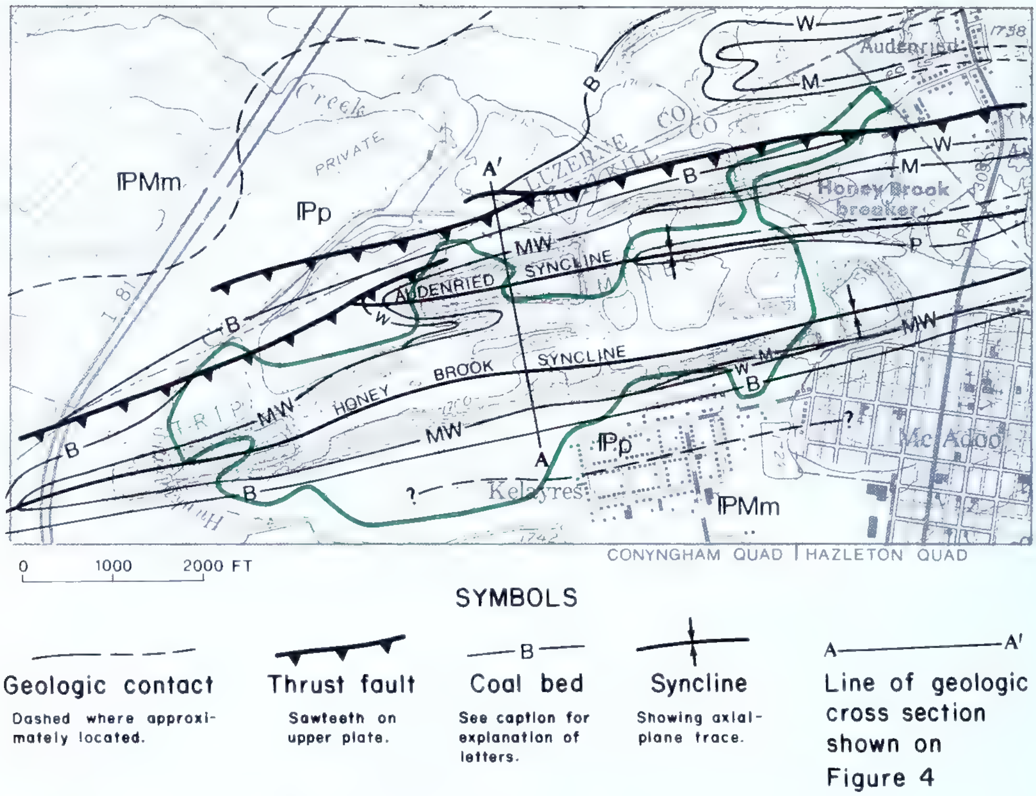

Figure 3. Geologic map of the Kelayres area (after Schasse and others, in preparation, and Inners, manuscript map). The colored line shows the approximate limits of the DER reclamation project area. Coal beds: B, Buck Mountain; W, Wharton; M, Mammoth; MW, Mammoth-Wharton; P, Primrose. Formations: ℙl, Llewellyn; ℙp, Pottsville; ℙMm, Mauch Chunk.

isolated coal basins that make up the Eastern Middle field (Inners, 1988; Figure 3). These basins are V-shaped to flat-bottomed downwarps that preserve the anthracite-bearing rocks of the Llewellyn Formation between upfolds of the conglomeratic Pottsville Formation and the red Mauch Chunk Formation. The Honey Brook syncline at Kelayres is of the V-shaped variety (Figure 4), and footwalls on either side of the stripping expose the steeply pitching "seatrock" of the Mammoth or combined Mammoth and Wharton seams. (Throughout most of the Kelayres stripping, especially in the western part, the Mammoth and Wharton coal beds were generally so close together as to constitute a single mined seam up to 40 feet thick.) Other coal beds that were once mined in the area include the Lykens (or Alpha), Buck Mountain, Gamma, and Primrose (Figures 3 and 4).

MINING HISTORY. Steep-pitch deep mining on the Wharton and Mammoth coal beds at the Honey Brook Colliery near the site of the Kelayres stripping was initiated in the early 1850's. By the turn of

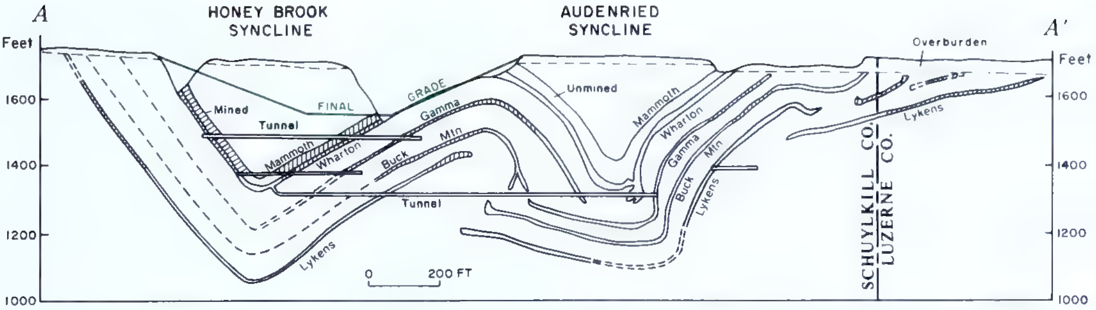

Figure 4. Mine-map cross section (modified from a section drawn in 1935 by the Glen Alden Coal Company) of the Kelayres strip mine area near line A-A′ on Figure 3. The colored line indicates the approximate final grade of the reclaimed slopes.

the century, when the mines were operated by the Lehigh and Wilkes-Barre Coal Company, both seams had been extensively worked. Although considerable stripping on the Mammoth-Wharton and other seams was done earlier (see quote from Roberts, 1901, above), the first major surface excavations at the Kelayres site took place in the late 1920's, when the Lehigh and Wilkes-Barre Coal Company dismantled the patch towns of Honey Brook No. 1 and Honey Brook No. 2 to get at the coal beneath (Druska and others, 1990). The gash that is now being backfilled, however, dates mainly from the stripping operations of Capparell Coal Company and Correale Mining Company during the period 1959–61 (Mike Druska, personal communication, 1990). These two companies removed all of the coal remaining in the Mammoth or Mammoth-Wharton seams down to the bottom of the synclinal basin for a distance of more than 6,000 feet in a northeast-southwest direction. In the slightly more than 100 years of deep and strip mining in the Mammoth-Wharton synclinal basin at Kelayres, a total of 2.5 to 3 million tons of anthracite was probably produced within the area that is now being reclaimed.

Subsequent to the stripping operations carried on in the early 1960's, the site remained in an unreclaimed state. In 1974, Beltrami Enterprises of Hazleton purchased the strip pit and a large tract of land to the north, but did no actual mining on the site. The huge, near-vertical highwall of the abandoned stripping, only a few tens of feet from homes in Kelayres, was "an accident waiting to happen." In November 1978, the accident happened. Twelve-year-old Gerald Pozza fell to his death while hanging over the highwall on a garden hose tied to a tree. As a result of this tragic fatality, the Kelayres strip mine soon became a high-priority reclamation site under the new federal Surface Mining Control and Reclamation Act.

RECLAMATION FUNDS. By the mid-twentieth century, 200 years of unregulated coal mining had left vast areas of Pennsylvania and more than 30 other states looking like veritable "moonscapes" of elongate craters and cone-shaped refuse piles. Pennsylvania took the lead in addressing the problem of these "abandoned mine lands" (AML) with the passage of the Land and Water Conservation Act of 1968. Nearly 10 years later, the U.S. Congress and President Jimmy Carter responded to the need for similar national legislation by passing and signing into law the Surface Mining Control and Reclamation Act of 1977. This act created the federal Office of Surface Mining (OSM) as an agency under the Department of the Interior. Title IV of the Act established a surcharge collection system to fund reclamation projects under the jurisdiction of OSM; the surcharges were established at 15 cents per ton on deep-mined coal and 35 cents per ton on surface-mined coal paid by active coal operators. Approximately $3 billion will be generated from the AML program nationwide over the 15-year authorized life of the program. Due to the Commonwealth's huge AML inventory—about one third of the national total—OSM funding in Pennsylvania has been directed to such health and safety priorities as the Kelayres project.

The Kelayres project is funded in Pennsylvania's 1988 AML grant from OSM. The reclamation contract was awarded to Geupel Construction Company, Inc., of Columbus, Ohio, on June 22, 1989. The $9 million funded for the project will not allow for backfilling to "original contour"; the north and south slopes as finally constructed will be about 2.5:1 (22 degrees) (see Figure 4). Completion of the Kelayres project, currently projected for Fall 1991, will eliminate one of the largest and most hazardous AML sites in the nation.

The authors thank John Bogash, Mike Druska, George Lenyo, and Mike Petresky for generously supplying historical information used in writing this article.

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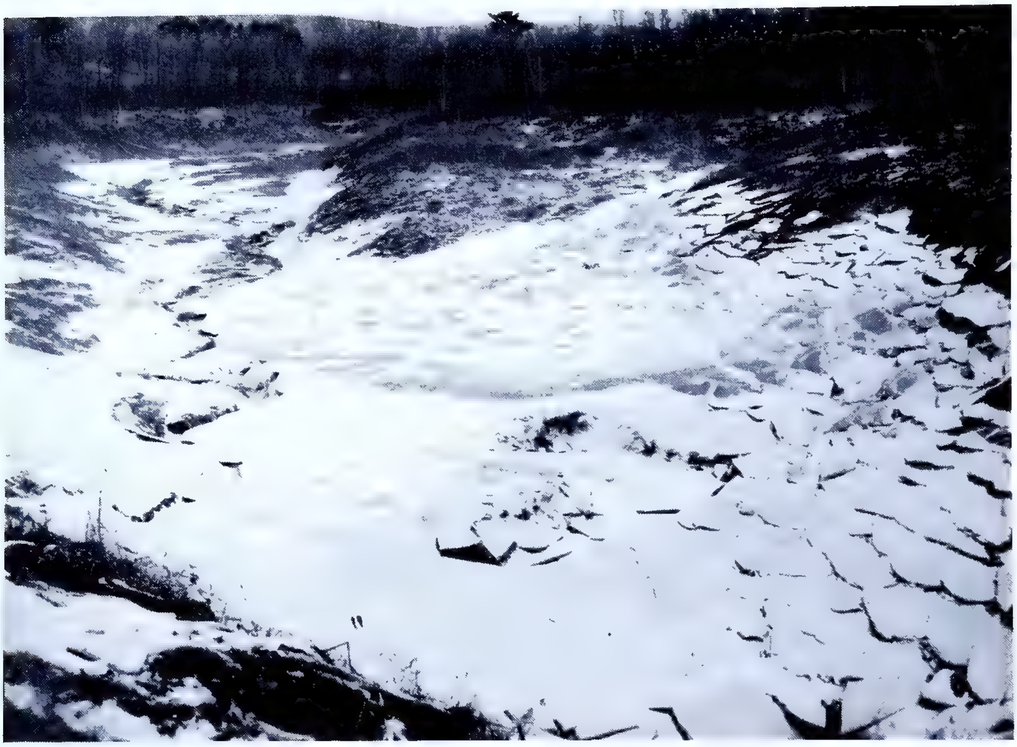
Schasse, H. W., Inners, J. D., and MacLachlan, D. B. (in preparation), *Geology and mineral resources of the Conyngham quadrangle, Luzerne and Schuylkill Counties, Pennsylvania,* Pennsylvania Geological Survey, 4th ser., Atlas 175b.

Geopics

A view from the west end of "The Sink," showing the stream that drains into the sinkhole. The sinkhole is visible just below the center of the photograph. Note the high-water mark along the upper right and the concentric polygons of broken ice resulting from the collapse. (See also the cover photograph and accompanying caption in this issue.) Photograph by W. E. Kochanov.



"Sunrise" *(continued from page 1)*

philosophy of registration could be used in evaluating the need for any type of professional registration.

The AEG report and draft model act are valuable resources and possible guides for those who advocate registration of geologists. The proof of public need and the public benefits of registration will be illuminated through the "sunrise" of an official review process.

Donald M. Hoskins

Donald M. Hoskins
State Geologist

NEW PUBLICATIONS

GROUNDWATER RESOURCES OF PIKE COUNTY

This recently released report, the latest in a series of reports dealing with the groundwater of Pennsylvania on a county basis, offers a detailed, yet easily understandable, description of groundwater in Pike County. Using data obtained from observations on hundreds of wells drilled in both bedrock and unconsolidated surficial material, the author effectively defines the quantity and quality of groundwater in the county. The report is replete with technical information such as depth of wells, depth to water, water-level fluctuations, well yields, transmissivity and storage-capacity test results of aquifers, and water-quality indicators such as specific conductance, hardness, pH, and concentrations of dissolved constituents. Methods of obtaining this information and its significance are clearly explained.

Two large colored maps of the county (1:50,000 scale, or 1 inch = 4,167 feet) show the distribution of bedrock units, elevation of the groundwater table, distribution of unconsolidated surficial deposits, and locations of wells. The water-bearing and water-quality characteristics of each rock unit are discussed in the text.

All of this information will be useful to the technical experts working with groundwater projects in Pike County, such as the engineers and hydrogeologists involved in developing new water supplies and the government officials and planners concerned with protecting future supplies. Furthermore, the clearly written introductory explanation of basic concepts such as geologic setting, hydrologic cycle, and groundwater occurrence makes the information presented in this publication understandable to the interested reader who is not a specialist.

Groundwater Resources of Pike County, Pennsylvania was written by Drew K. Davis of the U.S. Geological Survey. W. D. Sevon (Pennsylvania Geological Survey), Thomas M. Berg (Ohio Geological Survey), Lane D. Schultz (Allan A. Meyers, Inc.), and George H. Crowl (deceased; formerly with Ohio Wesleyan University) prepared the map of surficial geology, and Sevon, Berg, and Schultz prepared the map of bedrock geology. Published by the Pennsylvania Geological Survey, the report may be purchased from the State Book Store, P. O. Box 1365, Harrisburg, PA 17105-1365. The price is $17.75 plus $1.07 state sales tax for Pennsylvania residents. Prepayment is required; please make checks payable to *Commonwealth of Pennsylvania*.

—V. W. Skema

COAL RESOURCES OF CAMBRIA AND BLAIR COUNTIES

The Pennsylvania Geological Survey has recently published Mineral Resource Report 96, **Coal Resources of Cambria and Blair Counties—Part 1, Coal Crop Lines, Mined-Out Areas, and Structure Contours**. This compilation by Albert D. Glover consists of a series of topographic quadrangle maps reduced to a scale of approximately 1:62,500 and printed loose-leaf to fit conveniently into a three-ring binder. For each principal coal seam within a quadrangle, a separate map showing coal crop lines and the extent of strip and deep mining is included. A composite map containing crop lines of all principal coal seams, structure contours, and fold axes is also included for each quadrangle.

The coal resource information found in this report is needed not only for exploration and mining programs, but also for land use planning, land acquisition, and environmental planning. This report may help an investigator determine whether an area in Cambria or Blair County has been mined or whether it is underlain by coal that can be mined. Moreover, it will be of assistance in investigations of problems such as mine drainage and subsidence. The basic geologic framework of the parts of Cambria and Blair Counties underlain by coal is also presented in this report. By using coals as marker beds, the location and structure of other geologic units may be determined.

This report is available for $15.25, plus $0.92 sales tax for Pennsylvania residents, from the State Book Store, P. O. Box 1365, Harrisburg, PA 17105-1365. Orders must be prepaid; please make checks payable to *Commonwealth of Pennsylvania*.

—D. Yannacci

FOSSIL COLLECTING IN THE PITTSBURGH AREA

Students of earth science, professional geologists, and weekend fossil collectors take note. If you would like to go on a self-guided fossil-collecting trip around the Pittsburgh area and learn some geology at the same time, you are in luck! John Harper, a geologist with the Pennsylvania Geological Survey, recently led a field trip for the Pittsburgh Geological Society for which he prepared a 50-page guidebook entitled **Fossil Collecting in the Pittsburgh Area**. The field trip includes stops at three fossil-rich collecting sites in the Pittsburgh area as well as an outcrop-by-outcrop description of the geology along the route. The sites are (1) a quarry in the Connellsville sandstone containing fossil plant remains; (2) a roadcut exposure in the Ames Limestone in which an assemblage of offshore marine invertebrate fossils can be found; and (3) a mine spoil pile of Brush Creek shale that contains invertebrate fossils from a nearshore marine environment. All of these exposures are in Pennsylvanian-age lower to middle Conemaugh rocks. In addition to the geologic road guide and collecting-site descriptions, the guidebook contains a generously illustrated text in which the author details the geology of the Pittsburgh area, and a series of five plates in which over 100 line drawings of fossil life forms found in the Pennsylvanian-age rocks of western Pennsylvania are shown. So if you are looking for an educational activity that you can do alone or with friends or family in and around the Pittsburgh area, or if you just need a reference guide to help you identify some of the more common Pennsylvanian-age fauna and flora found in that part of the state, do not overlook this publication. The price of the guidebook is $5.00 plus $1.00 postage and handling. To obtain a copy, send a check (payable to *Pittsburgh Geological Society*) to the Pittsburgh Geological Society, P. O. Box 3432, Pittsburgh, PA 15230.

—J. R. Shaulis

GEOLOGIC MAP OF CHERRY AND GODFREY RIDGES, MONROE COUNTY

Map lovers and teachers of structural geology will greatly appreciate the new maps published by the U.S. Geological Survey on the geology of Cherry and Godfrey Ridges, Monroe County, Pennsylvania. The report includes two maps, which, when put together, measure 9 feet long, a challenge for mounting and display. The maps are published at a scale of 1:8,000. This large scale was chosen in order to adequately portray the extreme complexity of folding in an area largely covered by surficial and glacial deposits of Holocene and Wisconsinan age.

In easternmost Pennsylvania, the rocks that hold up Godfrey and Cherry Ridges have been deformed into upright to nearly recumbent folds with wavelengths averaging about 700 feet (213 m). Thirty-two stratigraphic units were mapped, aggregating 1,200 feet (365 m) in the northeastern part of the area and thinning to about 750 feet (230 m) in the west. Because the en echelon folds die out within short distances and plunge in different directions, and because the stratigraphic units are relatively thin, ranging from 5 to 180 feet (1.5 to 55 m) thick, the outcrop pattern on the two maps is complex and, in many respects, mimics larger structures in the Central Appalachians. These ridges contain a wide variety of easily distinguishable stratigraphic units, and, because of the complex folding, they have been used as a mapping area for geologic field courses.

Thirty-eight cross sections are included in this impressive publication. Teachers and students alike will treasure the map as a resource for teaching and learning about the folded structures of the Appalachians.

Map I–1422 by J. B. Epstein, entitled **Geologic Map of Cherry and Godfrey Ridges in the Saylorsburg, Stroudsburg, and East Stroudsburg Quadrangles, Monroe County, Pennsylvania,** is available from the U.S. Geological Survey, Map Distribution, Federal Center, P.O. Box 25286, Denver, CO 80225, for $6.20—a real bargain for a beautiful and useful map. For orders of less than $10.00, please include $1.00 for handling. Payment must accompany the order; please make checks payable to *Department of the Interior—USGS*.

—D. M. Hoskins

Surplus Topographic Maps

As a result of the ongoing program to revise and update Pennsylvania's topographic maps, we have received updated versions of 17 quadrangles. The outdated maps are being offered to anyone who has a use for them. We also have a number of orthophotomaps that are surplus. These surplus maps will be provided, at no charge, while they last. If you are interested in receiving some of these maps, please advise us how many different quadrangles and the number of each that you would like. Personal selection of quadrangles will not be possible. Address requests to:

Library
Department of Environmental Resources
Bureau of Topographic and Geologic Survey
P. O. Box 2357
Harrisburg, PA 17105-2357

Duplicate Publications Available

The Pennsylvania Geological Survey library has duplicate copies of the publications listed below. If you would like to receive copies of these publications, please write to us. Identify the publication that you want by the series and number, and send your request to Library, Department of Environmental Resources, Bureau of Topographic and Geologic Survey, P. O. Box 2357, Harrisburg, PA 17105-2357.

Geologic Quadrangle Maps

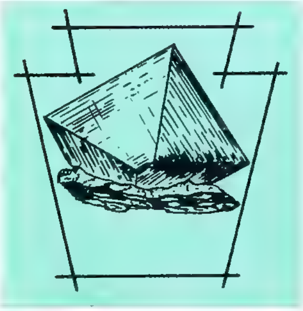
GQ-1003	*Geologic map of the Prosperity quadrangle, southwestern Pennsylvania,* B. H. Kent. 1972. 1 sheet, scale 1:24,000.
GQ-1054	*Geologic map of the Delano quadrangle, Schuylkill County, Pennsylvania,* G. H. Wood, Jr., and H. H. Arndt. 1973. 1 sheet, scale 1:24,000.
GQ-1067	*Geologic map of the Midway quadrangle, Washington County, southwestern Pennsylvania,* J. B. Roen. 1973. 1 sheet, scale 1:24,000.

Miscellaneous Investigations Series

I-699	*Geologic map of the Oak Forest quadrangle and part of the Blacksville quadrangle, southwestern Pennsylvania,* J. B. Roen. 1972. 1 sheet, scale 1:24,000.
I-715	*Geologic and coal-bed map of Clarion County, Pennsylvania,* E. D. Patterson and J. A. Van Lieu. 1972. 1 sheet, scale 1:62,500.
I-801	*Geologic map of the Beans Cove and Hyndman quadrangles and part of the Fairhope quadrangle, Bedford County, Pennsylvania,* Wallace de Witt, Jr. 1974. 1 sheet, scale 1:24,000, with explanatory pamphlet.
I-908	*Geologic map of the Avella quadrangle and part of the Steubenville East quadrangle, Washington County, Pennsylvania,* S. P. Schweinfurth. 1976. 1 sheet, scale 1:24,000.

Professional Paper

602	*Geology of the west-central part of the Southern Anthracite field and adjoining areas, Pennsylvania,* G. H. Wood, Jr., and others. 1969. 150 p.



EARTH SCIENCE TEACHERS' CORNER

by Tracey Gates

"Where Have All the Flowers Gone?"

"Where have all the flowers gone?" So goes the line from a familiar song. If you have thought about it, you are probably asking yourself, "What flowers?" Every spring our yards are ablaze with the colors of many flowers. Unfortunately, for as many flowers as you see blooming in your yard, there are upwards of two or three times as many endangered or threatened species of native wild plants being lost.

Pennsylvania has 3,340 known types of higher plants. Five hundred of these are either gone or in jeopardy. This means that more than 15 percent of ALL species in the state are listed as either extinct or on the brink of extinction, a disheartening loss.

Pennsylvania does not stand alone with this problem. In Hawaii, 97 percent of all native plants are threatened. Central America, which holds approximately 40 percent of all species on the earth, is in an especially critical position in the tropical areas.

So what do these statistics mean to you as science teachers? Hopefully, by seeing this very brief overview of a critical problem, I have piqued your curiosity. Geology and the other fields of natural and earth science that you teach are essential elements in preparing our young people to be responsible adults. Included in these essential elements are teaching about plant and animal extinction, long recognized in geologic history. To aid in this teaching, we offer the assistance of the Wild Resource Conservation Fund (WRCF). This fund is an independent agency in the state that was developed especially to help tackle problems of threatened species, and has been a supportive sponsor of many projects to study the "hows," "whys," "wheres," and "whens" of these problems and to recommend solutions. The WRCF has a variety of information on native wild plants and wildlife of Pennsylvania that can be made available to you. One of particular interest may be the program on "Rare and Endangered Wildflowers of Pennsylvania," which is available in slides or a video cassette format. The program will provide you with some sobering facts and statistics about the situation of our state's plant community.

Isn't it time that we worry about the condition of our own surroundings and how the loss of these plants will affect us as human beings? What better place to start than with information from the WRCF? The WRCF is here to help and inform. As teachers, I am sure you are always looking for issues to excite your students. What better way than to inform them of important issues here in their own state?

We suggest that you can be a leader in your school by informing your students about this sensitive yet crucial segment of the life cycle. Who knows, perhaps one of the students sitting in your class will become a scientist and develop answers to preserving endangered species.

To obtain a slide set or video cassette, or for more information, contact Wild Resources Conservation Fund, P. O. Box 1467, Room 101, Third and Reily Streets, Harrisburg, PA 17105-1467, telephone 717-787-1639.

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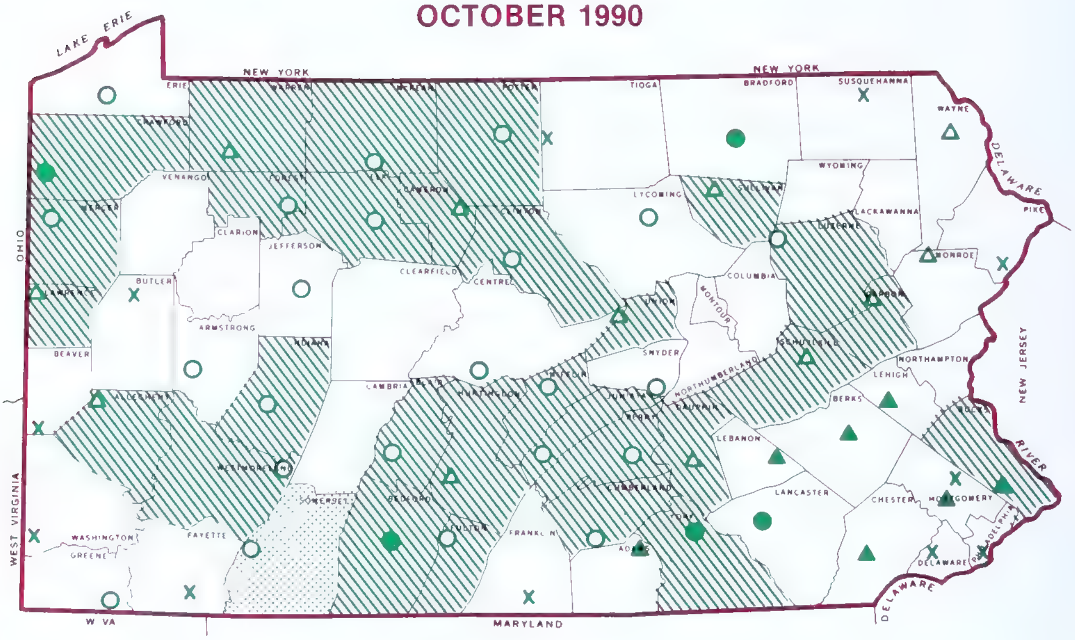
FOR
OCTOBER 1990



EXPLANATION

○ Above last year ● Below last year
Observation well

△ Above last year ▲ Below last year
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PENNSYLVANIA GEOLOGY

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PENNSYLVANIA GEOLOGICAL SURVEY VOL. 22/1

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ON THE COVER: Doubling Gap, Cumberland and Perry Counties, looking southwest. Blue Mountain, capped by the resistant Tuscarora Formation, "doubles back" on itself and forms a plunging anticline. The phenomenon may be related to a change in regional strike of about N50°E southwest of the gap to N80°E east of the gap. In the upper right background, Blue Mountain extends past the horizon, and the Great Valley is to its east (left). The town in the right foreground is Landisburg. Photograph by T. A. McElroy.

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Editors, Christine M. Dodge and Donald M. Hoskins.

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VOL. 22, NO. 1 **SPRING 1991**

JUL 15 1991

Past, Present, and Future

On January 19, 1971, the Pennsylvania Legislature established the Department of Environmental Resources. The department was born of the inevitable conflict resulting from an increasing population's growing demands on natural resources that are limited. Its charge was to define and reconcile the need of the public to use resources with the need to protect the environment of Pennsylvania. The Topographic and Geologic Survey of Pennsylvania was made part of the new department in recognition of the importance of geologic and topographic information in environmental protection and the responsible development and use of Pennsylvania's natural and mineral resources.

Following these two decades of public service, the department has been reorganized to better accomplish its charge. The Survey has been placed with the Bureaus of State Parks and Forestry in an organizational unit concerned with recreational and land resource issues. The role of the Survey has been, and will continue to be, collecting and analyzing geologic and hydrogeologic data to address public interests involving natural resources and environmental geology. Under the new organizational structure, the programs of the Survey will continue without major redirection.

The planned February, April, and June 1991 issues of *Pennsylvania Geology* are being combined into this spring issue. Future 1991 issues await a new budget for the upcoming fiscal year and a decision on whether to begin a subscription service.

More than 2,600 readers from Pennsylvania and 35 other states responded to our notice that the February issue of *Pennsylvania Geology* would not be published. Of those who responded, 98 percent asked to continue to receive *Pennsylvania Geology*. Of those, 72 percent said they would subscribe if a fee was necessary. We thank you all for your responses and your support.

We are very grateful to the nearly 1,100 respondents who wrote personal notes and suggestions for improving *Pennsylvania Geology*. Although 29 percent said no changes are needed or desired, for some time we have been considering format, size, sequence, and content changes. The comments we received will be a guide for us in deciding which changes, if any, will improve *Pennsylvania Geology*.

The Survey's assigned tasks of objectively defining, mapping, and reporting on Pennsylvania's geology and topography to support related public interests are not finished. Future decades will require at least as much as has been accomplished. Through our new organizational structure and through a reborn *Pennsylvania Geology*, we will proceed.

Donald M Hoskins

Donald M. Hoskins
State Geologist

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THE SECOND LEHIGH TUNNEL:

Geology and the New Austrian Tunneling Method

by Jack B. Epstein, U.S. Geological Survey, and
Patricia F. Buis, Pennsylvania Geological Survey*

The Northeast Extension of the Pennsylvania Turnpike (Pennsylvania Route 9) is a major traffic artery in eastern Pennsylvania, extending for 110 miles from the Pennsylvania Turnpike (Interstate Highway 276) near Philadelphia northward to Scranton. The four-lane highway narrows to two lanes at the approaches to the present Lehigh Tunnel through Blue Mountain, a nearly 1,000 foot high ridge at the boundary of Lehigh and Carbon Counties, about 13 miles north of Allentown and 1 mile southwest of Palmerton (Figure 1). Occasionally, this constriction has been the cause of miles-long traffic jams, especially during the summer months, when vacationers visit the Pocono Mountains. In February 1989, construction began on a second two-lane tunnel immediately west of the original. The tunnel

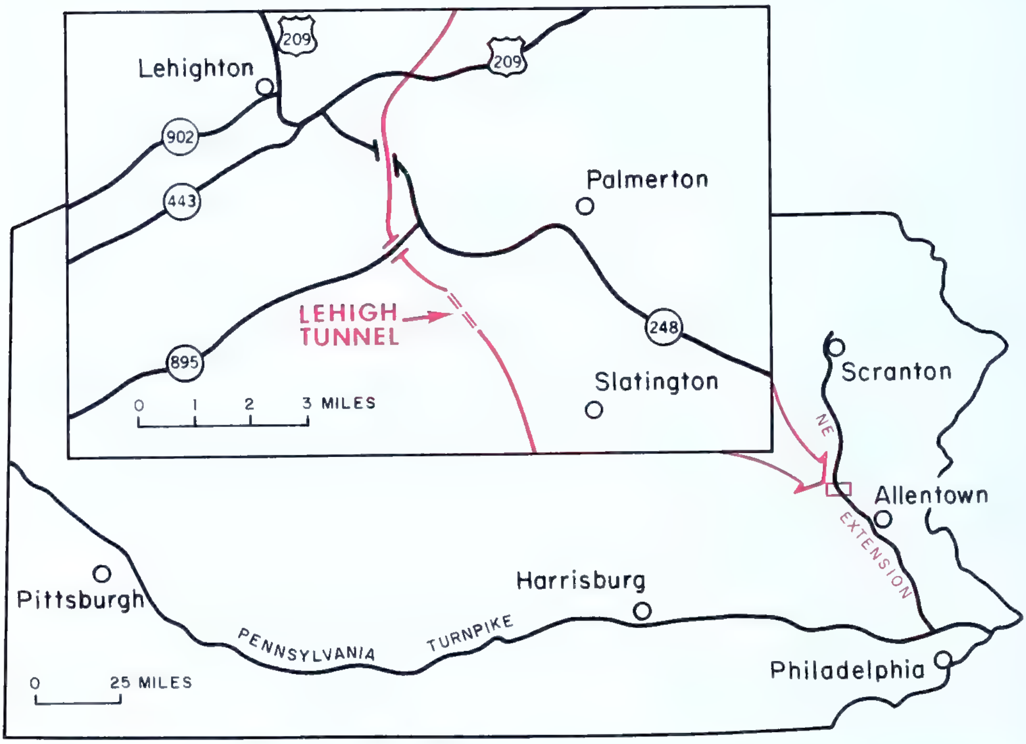


Figure 1. The location of the Lehigh Tunnel on the Northeast Extension of the Pennsylvania Turnpike.

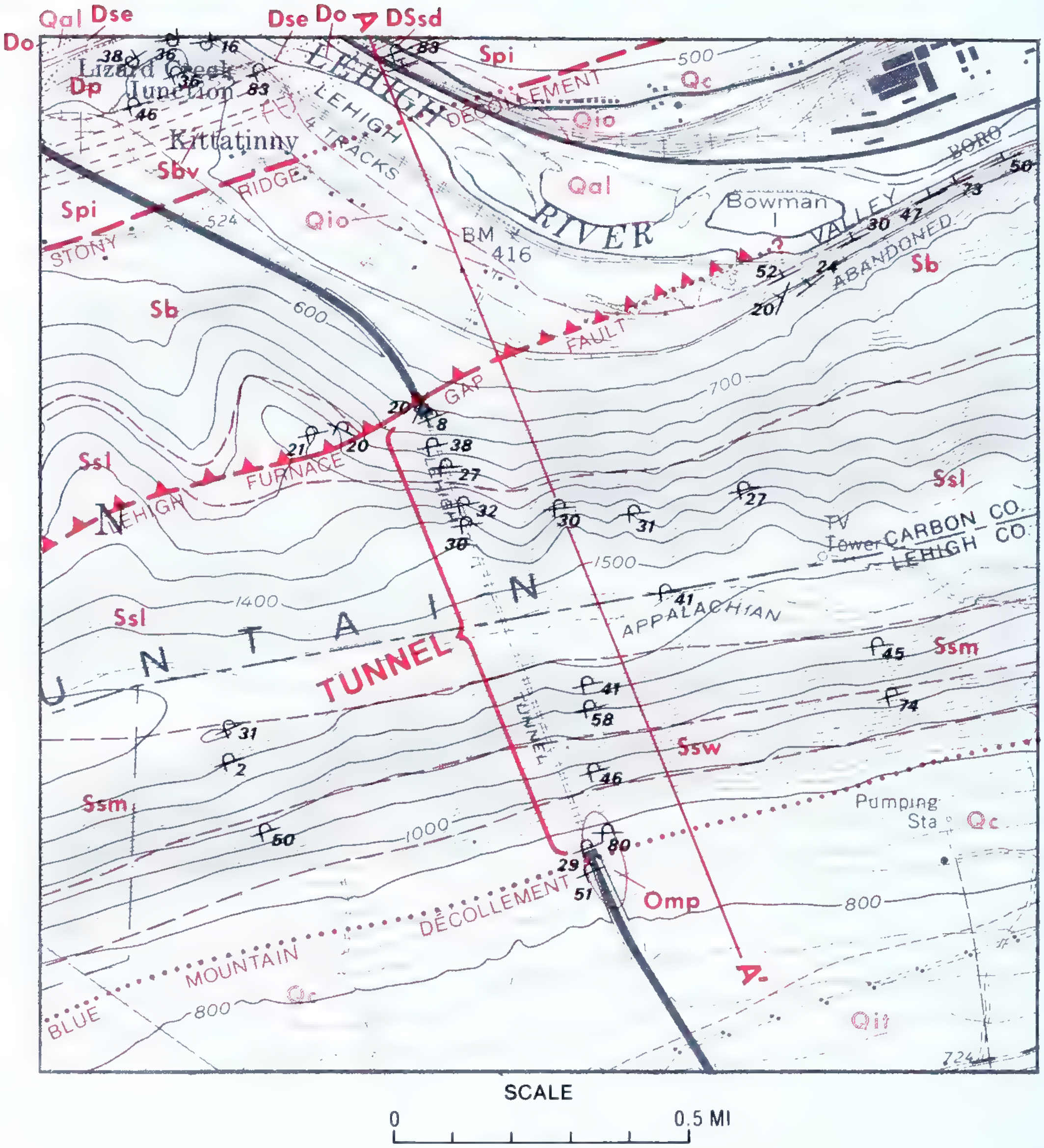
---

*Present address: 285 East Main Street, Apartment 5, Middletown, PA 17057.

has a projected cost of $37.8 million and will require the excavation of an estimated 200,000 cubic yards of material from Blue Mountain. It is expected to be completed and open for traffic in fall 1991 (Pennsylvania Turnpike Commission, oral communication, 1991).

Blue Mountain is part of a nearly continuous ridge that forms a natural barrier to the north and west of the Great Valley physiographic section through Pennsylvania from New Jersey into Maryland and beyond. At the tunnel site, slates and graywackes of the Martinsburg Formation are present at the south portal, succeeded northward by Silurian quartzites, conglomerates, and shales of the Shawangunk Formation and then by red and green sandstones, siltstones, and shales of the Bloomsburg Formation. These are further succeeded northward by a variety of Silurian and Devonian strata (Figure 2A). These rocks were complexly deformed during the late Paleozoic Alleghanian orogeny. The Martinsburg Formation was also affected by earlier Taconic (Ordovician) deformation and is separated from the younger Shawangunk Formation by an angular unconformity of regional extent. The orogenic episodes created folds, faults, cleavage, joints, surfaces of movement with slickenlines, and a variety of fractures filled with secondary quartz, calcite, and chlorite in the various units. At the unconformity in the tunnel, the Martinsburg is overturned and dips 35 degrees to the southeast, whereas the Shawangunk dips more steeply by 10 degrees and is also overturned to the southeast. No orogenic displacement has taken place at this contact or in adjacent rocks, as is evidenced at the contact exposed at Lehigh Gap, 2 miles to the northeast. At the north portal, the rocks of the Bloomsburg Formation have been rotated past 180 degrees so that they are overturned and dip to the northwest, as does the cleavage (Figure 2B; Epstein and Epstein, 1969; Epstein and others, 1974).

A topographic bench at an altitude of 1,100 feet on the north slope of the mountain, 0.4 mile west of cross section A–A′, marks the position of an imbricate thrust fault at which the overriding beds have been moved up to the northwest and subsequently folded so that the hanging wall is presently down to the northwest. The structure, the Lehigh Furnace Gap fault (Figure 2B), was shown in cross section by Epstein and others (1974) to cut bedding at very high angles. However, because the fault lies at a very low angle to the structural grain (Figure 2A), the fault is reinterpreted to be an imbricate fault that ramps up from a thrust subparallel to bedding in the Martinsburg Formation (Figure 2B). Several similar ramps have been mapped in the New Tripoli and New Ringgold quadrangles to the west, and the entire fault system in the Shawangunk and Bloomsburg Formations is now interpreted as a duplex. The ramps join the floor thrust in



EXPLANATION

Bedrock

Surficial

Geologic contacts

Dashed where approximately located; short dashed where inferred; dotted where concealed.

Thrust fault

Sawteeth on upper plate. Dashed where approximately located; short dashed where inferred; dotted where concealed.

24 Inclined

Vertical

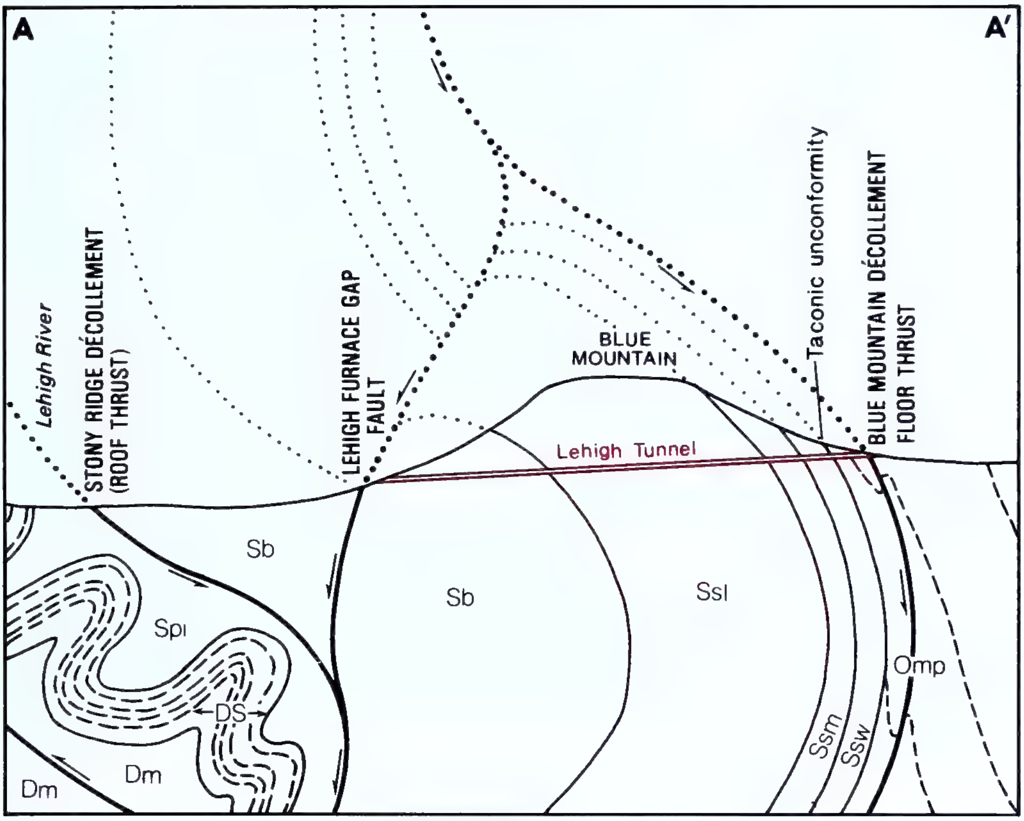
30 Overturned

Strike and dip of bedding

Décollement

Dashed where approximately located; dotted where concealed.

2A



2B

Figure 2. Geologic map and cross section at the site of the Lehigh Tunnel (modified from Epstein and others, 1974). A. Bedrock geologic map. B. Geologic cross section. Dashed lines in cross section show bedding within stratigraphic units; dotted lines show contacts projected above ground. Omp, Pen Argyl Member of the Martinsburg Formation; Ssw, Weiders Member of the Shawangunk Formation; Ssm, Minsi Member of the Shawangunk Formation; Ssl, Lizard Creek Member of the Shawangunk Formation; Sb, Bloomsburg Formation; Spi, Poxono Island Formation; DS, various units of Upper Silurian and Lower Devonian age; Dm, Marcellus Formation; Qit, pre-Illinoian till; Qio, pre-Illinoian outwash; Qc, colluvium; Qal, alluvium.

the Martinsburg with a roof thrust in the Bloomsburg, as depicted in Figure 2B. The roof thrust is not exposed, but it is interpreted to be present in the upper part of the Bloomsburg concealed beneath the valley of the Lehigh River. The new Lehigh Tunnel passed through a fault zone, which is believed to be the floor thrust in the Martinsburg, about 350 feet south of the contact with the Shawangunk Formation. This zone is about 27 feet wide and contains intensely sheared and rotated rocks with abundant quartz veins (Figure 3). If this zone is, in fact, the floor thrust of a duplex, it must extend for many miles to the northeast and southwest, parallel to the south slope of Blue Mountain. However, it has only been seen in the tunnel—elsewhere

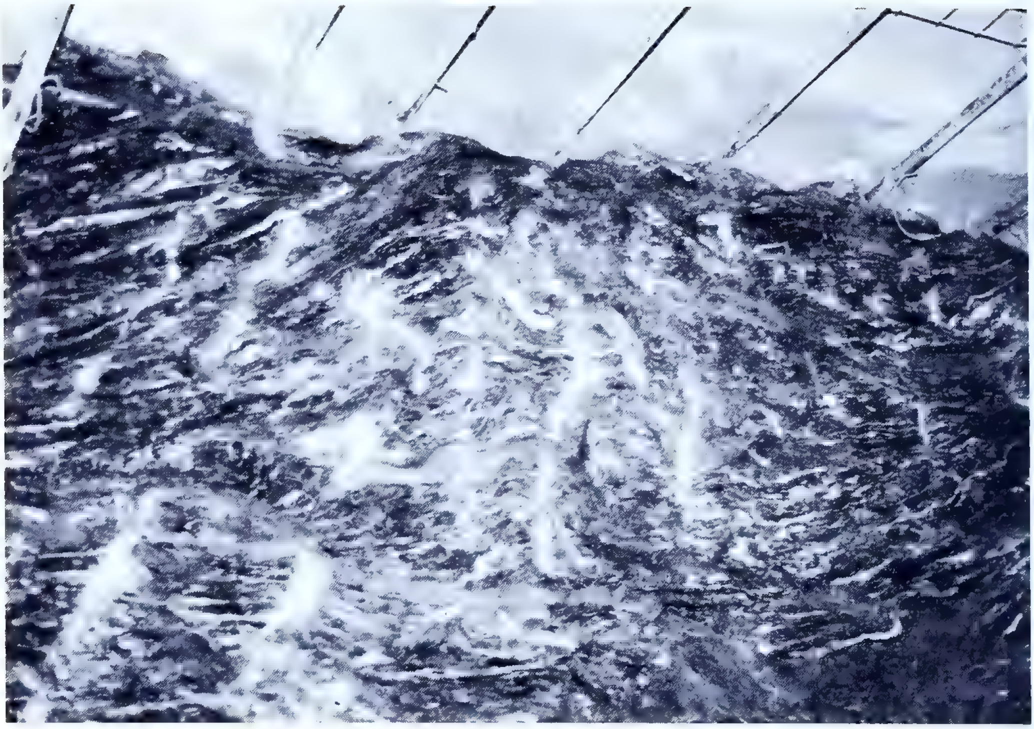


Figure 3. Shear zone in the Martinsburg Formation exposed in the new Lehigh Tunnel on January 24, 1990, believed to be the floor thrust of a duplex in the Shawangunk and Bloomsburg Formations. Welded wire fabric and spilling pipes at the top are part of the "shotcrete" canopy used to reinforce the tunnel crown and protect the tunnel opening.

the strata that would contain it are buried by thick colluvium and glacial deposits. The floor and roof thrusts may coincide with detachments that have been interpreted to separate lithotectonic units of differing structural characteristics—the Blue Mountain décollement and Stony Ridge décollement, respectively (Figure 2B).

On the north slope of the mountain, at least 15 feet of colluvium was exposed during construction, although in places nearby it is as much as 50 feet thick. The colluvium consists of a mixture of shale and sandstone fragments up to 1 foot long in a pale-reddish-brown silty matrix. No glacial deposits were seen there. On the south side of the mountain, however, the surficial materials consist of a thicker apron of deeply weathered yellowish-brown colluvium and grayish-orange to reddish-brown till, probably of pre-Illinoian age (see Epstein and others, 1974, p. 223). The Martinsburg Formation immediately under the till is also weathered to depths of as much as 50 feet. During preliminary construction in the fall of 1989, a series of small, tight, overturned kink folds was exposed in the Martinsburg just under the till, a few hundred feet south of the tunnel portal (Figure 4). These

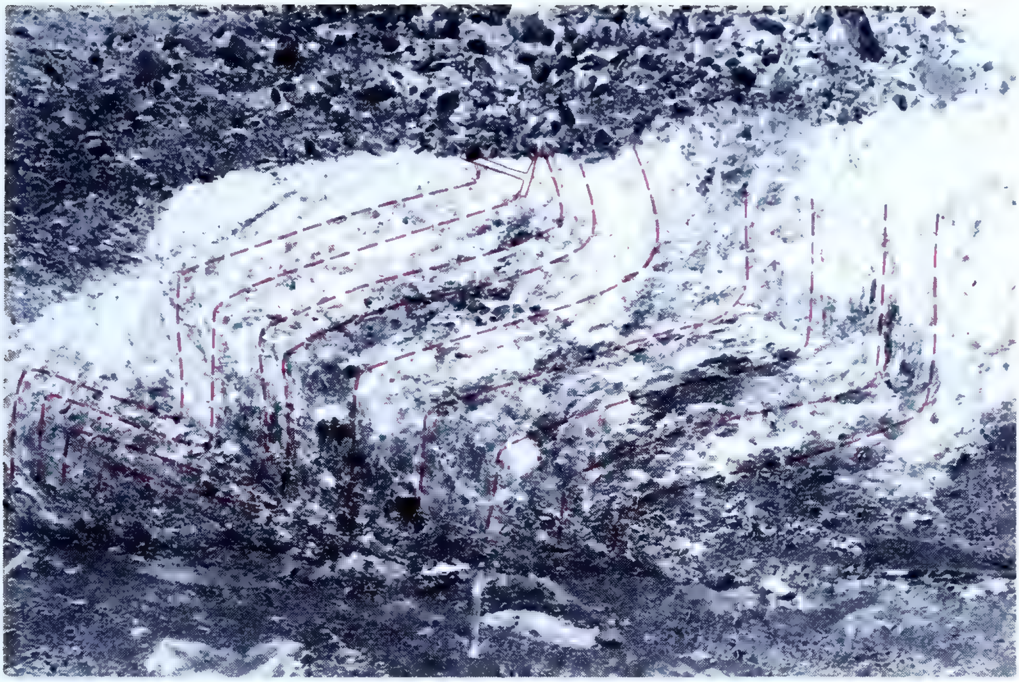


Figure 4. Folds, possibly produced by ice push, in weathered Martinsburg Formation slates underlying pre-Illinoian till near the Lehigh Tunnel on the south slope of Blue Mountain. View looking westward. Hammer gives scale.

folds have wavelengths of about 13 feet and amplitudes of 1 to 2 feet. They verge to the south, opposite to the regional tectonic folds that verge to the northwest. The folds may have formed either by downslope creep or in response to ice push by an overriding pre-Illinoian glacier. The orientation of the fold axes is approximately N60°W, about 45 degrees from the trend of the ridge, which is N75°E. This orientation suggests, but does not prove, a glacial origin for the folds.

The geologic structures found in Blue Mountain created a variety of problems for tunnel construction. An innovative European engineering technique, the New Austrian Tunneling Method (NATM), was used to cut through these rocks. NATM differs from other tunneling techniques in several ways. The tunnels are lined with strengthening material, including rock bolts, welded wire mesh, and lattice girders, immediately after a few feet are excavated, and covered with pneumatically emplaced concrete, or "shotcrete" (Associated Pennsylvania Constructors, 1989). The advantage of this technique is that the rock mass surrounding the tunnel becomes self supporting, so the need for conventional steel support beams is eliminated, thus reducing the costs of construction significantly. Because of this process, the final cross-sectional shape of the tunnel is elliptical, rather than the conventional parallel-sided horseshoe shape (Figure 5).

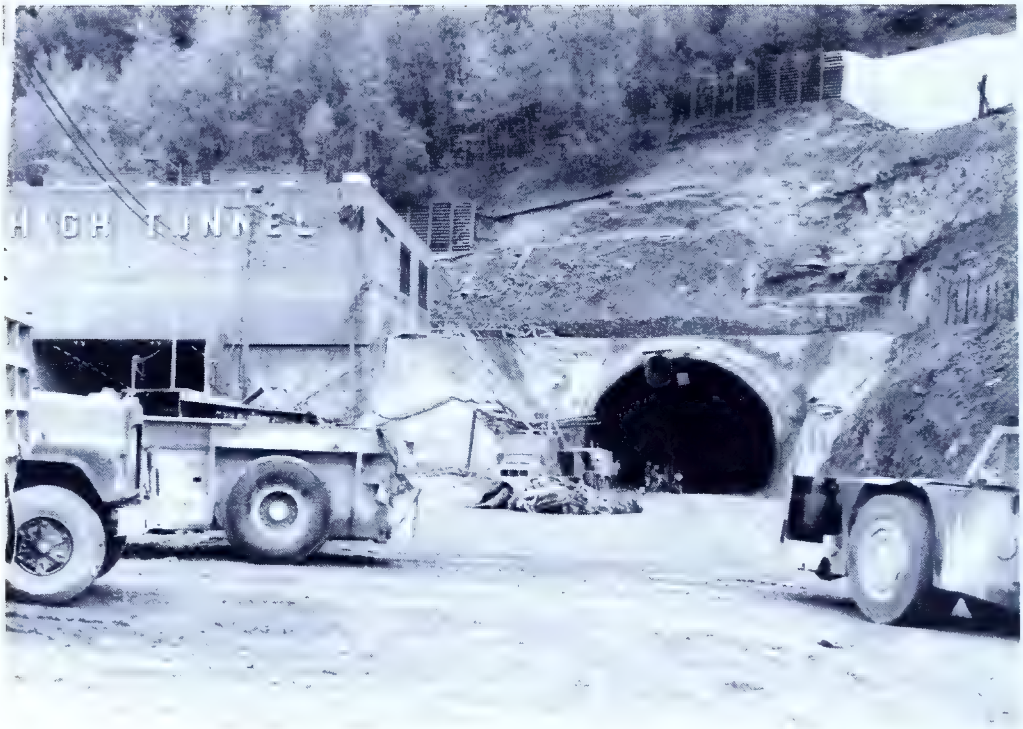


Figure 5. North portal of the second Lehigh Tunnel excavated in the Bloomsburg Formation. Bedding is overturned and nearly recumbent. Note the elliptical shape of the tunnel bore, a diagnostic feature of the New Austrian Tunneling Method.

As part of NATM procedures, continuous pressure and convergency readings must be taken during the tunneling to monitor rock behavior. These readings gauge the amount of support needed at any particular location in the tunnel. Overall, the Martinsburg Formation has required the most support and the Shawangunk Formation the least. However, variations in local rock characteristics have prevented setting definite support limits for each rock unit.

Excavation of the tunnel proceeded from both sides of the mountain and was guided by laser beams positioned by satellite telemetry. The tunnel "holed through" on June 13, 1990, and Ken Pukita, the project manager, noted that the two laser beams coming in from opposite ends of the tunnel were off by only a couple of inches.

The Pennsylvania Turnpike was built 50 years ago as the nation's first four-lane superhighway. For many years, however, two-lane tunnels provided an obstacle to the efficient flow of traffic. In recent years, such impediments have been removed from the Turnpike's main line by the burrowing of parallel tunnels to allow four lanes of traffic, and by rerouting segments of the highway, allowing the elimination of some tunnels. The completion of the second Lehigh Tunnel this fall will remove the last of these impediments on the Pennsylvania Turnpike and provide for more efficient travel along the corridor between Philadelphia and Scranton.

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NEW PUBLICATIONS

OIL AND GAS DEVELOPMENTS IN PENNSYLVANIA IN 1989

The Pennsylvania Geological Survey's annual summary of developments in the oil and gas industry for 1989 has recently been released as Progress Report 203. This publication includes news of the industry, such as information on production and reserves, drilling and well completions, and exploration and development. A lengthy table contains summarized records of wells that penetrated rocks of Middle Devonian or older age. The report also includes information on Survey developments that might assist the industry, such as current research on oil and gas resources and the availability of Survey publications and open-file reports that are concerned with these commodities.

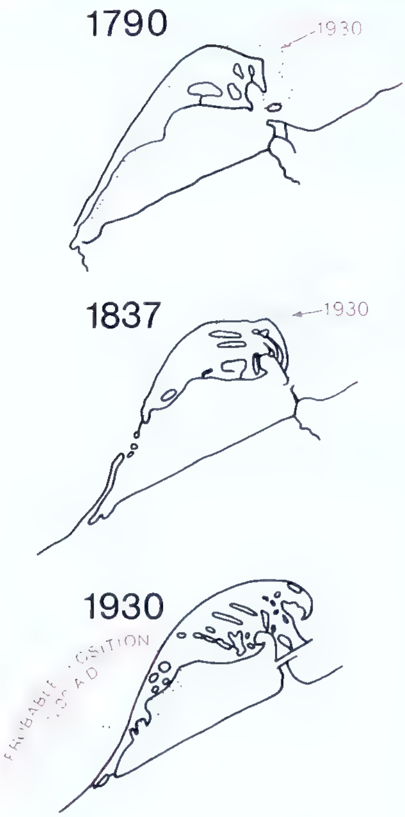
According to this report, there was a general decline in productivity and activity in the oil industry in Pennsylvania in 1989. Production decreased by 7.3 percent from the previous year to 2,601,982 barrels, reserves decreased by 3.6 percent to 41,563,000 barrels, and the total number of wells drilled decreased by 14 percent to 1,527. Sixty-seven percent of those wells were in Warren County, which also led the state in production with 827,916 barrels, or 31.8 percent of the state's total. In contrast to the overall trend for Pennsylvania, that production is 28.3 percent higher than Warren County's production in 1988. Other counties showing increases in production in 1989 were Allegheny, Butler, Clarion, Clearfield, and Jefferson.

The number of gas wells decreased by 19 percent from the previous year, and gas reserves decreased slightly, but gas production rose by 14.8 percent. Seventy-five percent of all gas wells drilled in Pennsylvania were in Warren, Indiana, Venango, Armstrong, Crawford, Erie, Clearfield, and Clinton Counties.

Progress Report 203, **Oil and Gas Developments in Pennsylvania in 1989**, by John A. Harper and Cheryl L. Cozart, is available by mail for $3.25, plus 20¢ sales tax if mailed to a Pennsylvania address, from the State Book Store, 1825 Stanley Drive, Harrisburg, PA 17103. Orders must be prepaid; please make checks payable to *Commonwealth of Pennsylvania*.

—J. H. Barnes

GUIDE TO PRESQUE ISLE STATE PARK



An illustration from Park Guide 21 showing the growth of Presque Isle (modified from Jennings, O. E., 1930, Carnegie Magazine, v. 4, p. 171-175).

Named by the French during the eighteenth century, Presque Isle— literally meaning "almost an island"—is rich in history, wildlife, and recreational opportunities. Yet, as revealed in newly issued Park Guide 21, entitled **Presque Isle State Park, Erie County—A Dynamic Interface of Water and Land**, this picturesque area is much more and affords a rare opportunity to view some of the Commonwealth's recent geologic past and various geologic processes actively at work today. As noted by the author, staff geologist Helen L. Delano of the Pennsylvania Geological Survey, Presque Isle, a peninsula and recurved spit, consists of many environments—including beaches, dune ridges, interdune ponds and marshes, and sheltered harbor—all of which are affected and modified through time by the ceaseless actions of waves, currents, and wind.

The 13-page park guide contains a comprehensive overview of the geologic history and depositional environments of Presque Isle and the roles that different geologic processes and human interactions have on modifying its landforms. Topics covered include the origin, growth and migration, and present profile of Presque Isle. Processes responsible for the erosion, transport, and deposition of sediment in different localities are also discussed. Weather and climate are shown to have a profound effect on rates of erosion. It is not surprising that man has endeavored to control erosion and stabilize beaches here for more than a century; the methods employed and their relative success are succinctly summarized. The author concludes that "wise recreational use of this unique coastal land requires careful planning to balance the demands of maintaining public access and service facilities against the possibilities of damaging the complex system of interacting forces which is the shoreline environment."

Published by the Pennsylvania Geological Survey, Park Guide 21 was prepared in cooperation with the Bureau of State Parks, Department of Environmental Resources. It is available free at Presque Isle State Park, or upon request from the Pennsylvania Geological Survey, Department of Environmental Resources, P. O. Box 2357, Harrisburg, PA 17105-2357.

—C. H. Dodge

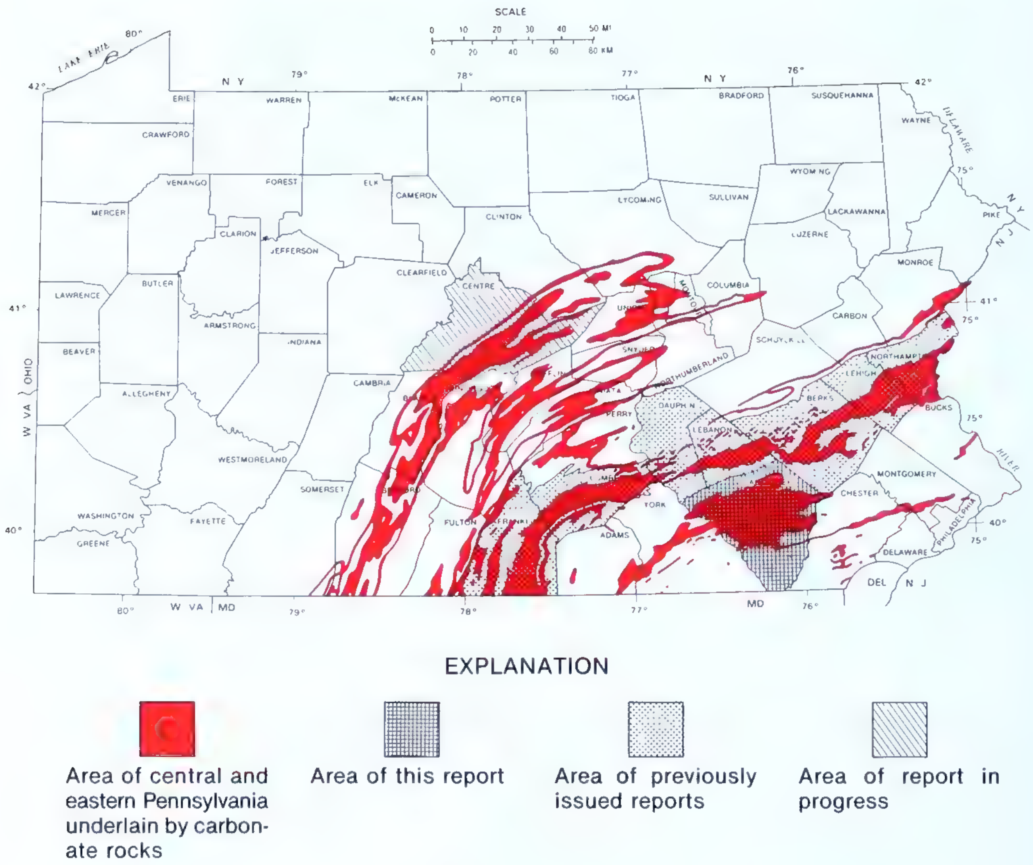
SINKHOLES AND KARST-RELATED FEATURES OF LANCASTER COUNTY

All too often, Pennsylvanians find that what seems to be solid ground under their roads and buildings is anything but solid. Unexpected openings of sinkholes annually cost Commonwealth citizens and businesses thousands of dollars, lost time, and, in some cases, personal injury.

Thanks to a program launched in 1985 by the Pennsylvania Geological Survey, it may be possible to avoid problems caused by sinkholes. The purpose of the program is to identify areas of carbonate bedrock in Pennsylvania that are susceptible to sinkhole development and areas that have a reported history of sinkhole occurrence. The data can be used to develop information leading to preliminary site investigations for land use and development.

To disseminate the information as rapidly as possible, project results are published as open-file reports on a county-by-county basis. The eighth report of the series, Open-File Report 90-01, **Sinkholes and Karst-Related Features of Lancaster County, Pennsylvania,** compiled by staff geologist William E. Kochanov, has recently been released.

The report consists of a brief explanatory text and eighteen 7.5-minute (1:24,000 scale) topographic quadrangle maps. The text contains an introduction, a description of methods used in compiling the report, references, and a glossary. The maps show depressions



(closed, semiclosed, and linear), sinkholes, surface mines, cave entrances, and bedrock geology.

The report may be examined at the offices of the Pennsylvania Geological Survey, 9th floor, Executive House, 101 South Second Street, Harrisburg. Copies of the report may be purchased by mail at the prepaid copying and shipping cost of $45.00, plus $2.70 sales tax if mailed to a Pennsylvania address. Send mail orders to the Pennsylvania Geological Survey, P.O. Box 2357, Harrisburg, PA 17105-2357. Checks should be made payable to *Commonwealth of Pennsylvania*.

—T. A. McElroy

AAPG PUBLISHES LEIDY GAS FIELD REPORT

As a paper in the first volume of its new series of publications, the *Atlas of Oil and Gas Fields* (part of the *Treatise of Petroleum Geology*), the American Association of Petroleum Geologists (AAPG) has recently released a comprehensive report on the Leidy gas field in Clinton and Potter Counties, north-central Pennsylvania. Authored by John A. Harper, Chief of the Oil and Gas Geology Division of the Pennsylvania Geological Survey, the study contains a detailed account of the history, structure, stratigraphy, trap mechanisms, reservoir characteristics, source beds, and exploration concepts of this historically important gas field. A number of atlases based on trap type are planned and will include several hundred studies of various oil and gas fields worldwide. Three atlases have been published to date.

The Leidy gas field is particularly noteworthy because of the large quantities of natural gas that it produced and because it ushered in a new period of intense oil and gas exploration and development in the Appalachian basin commencing in 1950. The Leidy field consists of six pools, five of which are in the Lower Devonian Ridgeley Sandstone and one in the Upper Devonian Lock Haven Formation. The pools are situated along both flanks of the thrust-faulted Wellsboro anticline and cover an area of more than 24,000 acres. Leidy is considered to be a "deep" gas field with well depths typically exceeding 5,500 to 6,000 feet. Ridgeley Sandstone reservoirs have a combination of structural and diagenetic (i.e., porosity changes) traps, whereas those of Lock Haven reservoirs are chiefly stratigraphic and diagenetic.

The success of the Leidy field was the result of the discovery of gas in the Ridgeley Sandstone, the principal reservoir, in 1950. Although most of the Ridgeley reservoirs were exhausted by 1959 and thereafter converted to storage, the ultimate recoverable reserves in the Ridgeley Sandstone are estimated at 175 billion cubic feet. Ridgeley pools in the Leidy field generally produced large amounts of gas, but were relatively short lived. Some of the Ridgeley wells were spectacularly successful, and one holds the record of the largest official open flow in the Appalachian basin—a reported natural open flow of 145 million cubic feet of gas per day! High-pressure blowouts were a potential hazard in the Leidy field, and the services of none other than "Red" Adair, the famous well-fire expert, were required on at least three separate occasions.

Harper concludes that the lack of suitable structures combined with sufficient porosities makes it unlikely that Ridgeley pools similar to those in the Leidy field will be found elsewhere in north-central Pennsylvania. On the other hand, he notes that the Lock Haven Formation has only recently been recognized as a potentially good reservoir; little development in this formation has occurred prior to 1980. Lock Haven sandstones have been shown to be good reservoirs for both natural gas and oil in the vicinity of the Leidy field. Because it appears to be the best hope for future recoverable reserves in the area, the author recommends thorough test drilling of the Lock Haven Formation throughout north-central and northeastern Pennsylvania.

This report will be of value to geologists interested in detailed field studies illustrating various ways oil and gas are trapped within Pennsylvania and the Appalachian basin. It will also be of use to anyone concerned with the history of oil and gas geology.

All studies in the *Atlas of Oil and Gas Fields* follow a standard format. Texts are concise yet comprehensive. Illustrations are abundant. Detailed "census" information on field description and production data is summarized in two appendices.

Harper's report, entitled *Leidy Gas Field, Clinton and Potter Counties, Pennsylvania*, was published in 1990 in the volume **Structural Traps I—Tectonic Fold Traps**, compiled by E. A. Beaumont and N. H. Foster. The book can be purchased for $39.00, plus $5.75 for shipping, by writing to the AAPG Bookstore, P. O. Box 979, Tulsa, OK 74101-0979, or by telephoning 918-584-2555. Prepayment is required; please make your check or money order payable to *AAPG Bookstore.* All major credit cards are accepted.

—C. H. Dodge

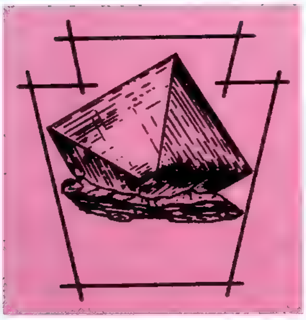
LIST OF U.S. GEOLOGICAL SURVEY REPORTS FOR PENNSYLVANIA AND NEW JERSEY

The U.S. Geological Survey is currently publishing a new series of bibliographies that provide comprehensive geologic information on either a state or regional geographic division. These new bibliographies are produced for the U.S. Geological Survey by the American Geological Institute. Indexed bibliographies have been prepared for Alaska, California, Colorado, Utah, and the Pennsylvania-New Jersey area. Nonindexed lists have been prepared for Arkansas, Florida, New York, Oregon, and the Massachusetts-Rhode Island-Connecticut area.

The list contains reports and maps published by the U.S. Geological Survey relating to the geology and mineral and water resources of Pennsylvania and New Jersey from 1879 to July 1988. Publications released after July 1988 can be found through the monthly catalog **New Publications of the U. S. Geological Survey**. These bibliographies include annual reports, professional papers, circulars, bulletins, water-supply papers, yearbooks, monographs, water-resource investigations, reports available only through NTIS (National Technical Information Service), and maps, charts, and atlases. The individual reports are listed sequentially by report series, and complete bibliographic citations are included. The bibliography is indexed in two parts, a general subject index and an author index.

This new, comprehensive bibliography is available for $2.50 from U.S. Geological Survey, Books and Open-File Reports, Box 25425, Denver, CO 80225. Prepayment is required; please make checks or money orders payable to *U.S. Geological Survey*.

—*D. M. Hoskins*



EARTH SCIENCE TEACHERS' CORNER

Rock Collecting in Pennsylvania Made Easy

If you would like to have a rock set containing the common rock types that crop out in Pennsylvania but do not have the several weeks of free time needed to collect them, or do not want to drive your car 1,000 miles with one eye on the road and the other on a geologic map, or do not want part of your house or garage to be taken over by a pile of rocks while you try to decide which specimens to keep or throw away, do not despair. During a recent sabbatical leave, Alfred C. Palmer, Penncrest High School teacher and Widener University adjunct professor, has taken care of all of this for you. He has compiled 500 sets of rock samples (each sample measures approximately 2 by 2+ inches), complementing Pennsylvania Geological Survey Map 63, *Rock Types of Pennsylvania*. He also authored an accompanying booklet containing a discussion of the important geologic characteristics and significance of each sample, along with a photograph of the outcrop from which the sample was taken.

The rock set includes 24 samples, Pennsylvania Geological Survey Map 63, and the descriptive booklet. The cost per set is $30.00. Institutions desiring four or more sets may purchase them for $25.00 each.

The project received support from the Pennsylvania Geological Survey, Widener University, the Pennsylvania Science Teachers Association, and the Pennsylvania Department of Education. All proceeds from sales of the sets are being deposited in an account at the Delaware County Institute of Science. They will fund a Pennsylvania Geoscience scholarship.

Orders for the rock sets should be addressed to A. C. Palmer, Penncrest High School, 134 Barren Road, Media, PA 19063. Orders must be prepaid; please make checks payable to *The Delaware County Institute of Science.*

—J. R. Shaulis

Environmental Education: A Private Sector Initiative

A professional two-week course will be offered July 15–26, 1991, for science teachers (K–12) and administrators, focusing on **Issues in Environmental Education** that will be critically important in the 1990's. The course will familiarize participants with hazardous waste, landfills, radon, nuclear and alternative forms of energy usage, groundwater contamination and cleanup, and educational resources available to science teachers. The comprehensive lecture- and field-based workshop will be conducted by staff scientists of R. E. Wright Associates, Inc. (REWAI), supplemented by scientists and engineers from local industries and governmental agencies. The workshop will be held at REWAI's Learning Center of Applied Environmental Technology, 3240 Schoolhouse Road, Middletown, Pennsylvania. Financial support for the associated course fees may be available from Title II (Eisenhower) funds through local school districts or through Intermediate Units. For further information and registration materials, call Dr. Marvin E. Kauffman, 717–944–5501 or 800–331–6491.

REMINDER!

We are in the process of revising the circulation list for *Pennsylvania Geology* based on returns to the letter and questionnaire that were sent to all readers in March 1991. If you have not returned your form and wish to continue receiving *Pennsylvania Geology*, please return the form as soon as possible. All readers who have not responded by August 1, 1991, will be dropped from our circulation list.

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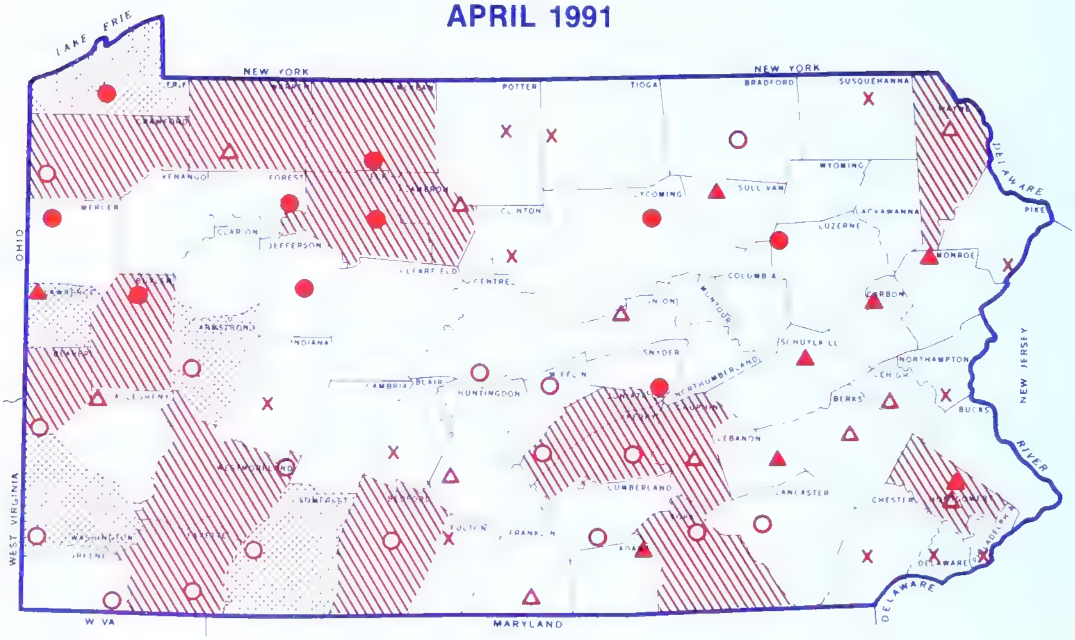
FOR
APRIL 1991



EXPLANATION

○ Above last year
● Below last year
Observation well

△ Above last year
▲ Below last year
Observation well equipped with data-collection platform

✕ No data

▨ High

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ON THE COVER

The Lower Falls of Wapwallopen Creek at the "Powder Hole," near Wapwallopen, Luzerne County. This was the source of water power for the Wapwallopen mills (1859–1912) of the Du Pont black powder company. The notch on the cliff to the left of the falls held a wooden flume that carried water to several industrial buildings on the east bank of the creek. On the right, an iron penstock led down to a turbine in the power house. The creek here cuts through a resistant rib of gray siltstone of the Trimmers Rock Formation that projects westward into a drift-filled preglacial valley. Photograph by Jon D. Inners.

PENNSYLVANIA GEOLOGY

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Contributed articles are welcome; for further information and guidelines for manuscript preparation, contact D. M. Hoskins at the address listed above.

Articles may be reprinted from this magazine if credit is given to the Bureau of Topographic and Geologic Survey.

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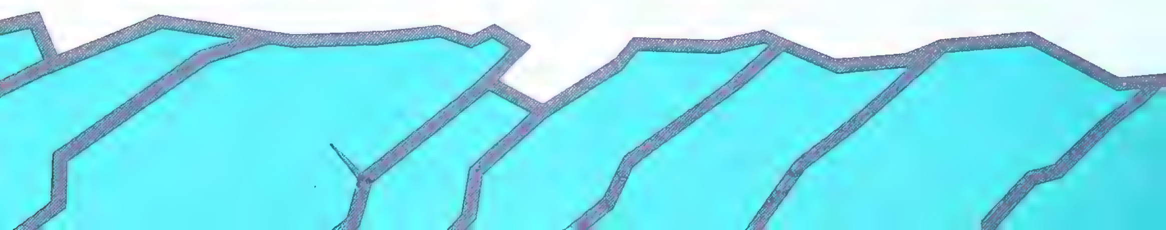

STATE GEOLOGIST'S EDITORIAL

Pennsylvania Geology Returns

With this issue of *Pennsylvania Geology*, we return to a regular schedule of publication. In the scale of geologic time, the past year during which we temporarily suspended publication is but a microsecond and would hardly be noticed. Some of you, however, have noticed and have written, inquiring of our plans. We thank you! It is to you, and the more than 2,000 others who responded to our notice of publication cessation, that we address these comments and the contents of this and future issues.

You will notice some changes. Our new cover design allows use of geological photography that would not have easily fit in the prior design. We have also redesigned the inside covers and outside back cover as well as the text format. The map of groundwater levels previously printed on the back cover will no longer run in each issue, but will be supplanted by other informational and timely maps. The annual listing of ongoing geological research in Pennsylvania and recently published geological reports will no longer be printed in *Pennsylvania Geology* because it is directed to only a limited number of our readers. A newsletter, jointly sponsored by Pennsylvania's geological societies, will take the place of the former research issue of *Pennsylvania Geology*.

For the next year or two, we will follow the seasons and have four issues per year. If there is sufficient interest and sufficient quality material for publication, we will consider returning to a bimonthly schedule at a later date. We remind our readers that *Pennsylvania Geology* is not solely intended as an outlet for Survey staff writers. We solicit your assistance through timely, interesting, and quality articles on geological subjects that you may wish to submit. You may also participate in the future of *Pennsylvania Geology* through submission of high-quality photographs of geological subjects. A geologically oriented photograph with sharp focus and good contrast, and a 50-word description of the subject, including location and scale, will be considered for cover or text publication.

Donald M. Hoskins

Donald M. Hoskins
State Geologist

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IN MEMORIAM

John Peter Wilshusen

1930–1991

Peter Wilshusen, retired chief of the Environmental Geology Division of the Pennsylvania Geological Survey, died at his home on September 23, 1991, after a prolonged battle with cancer. The fact that Pete lived as long as he did after contracting the illness is a tribute to both his positive attitude and the deep love given to him by his family and many friends.

Pete, a graduate of the New Mexico Institute of Mining and Technology and the South Dakota School of Mines, was a geologist with the Survey for 25 years. His accomplishments with the Survey were previously reviewed (*Pennsylvania Geology*, v. 21, no. 5, p. 1), but his guide entitled *Geology of the Appalachian Trail in Pennsylvania* is mentioned here because in a sense it is emblematic of Pete. Pete was a geologist. He loved nature and outdoor activity with their inherent challenges. He was an avid hiker and bicycler. His desire to share his enthusiasm and knowledge with others led him to prepare the Appalachian Trail guide. He not only knew the geology of the Trail in Pennsylvania, he hiked the Trail and helped to maintain a section of it. His contribution will continue to bring pleasure to others for years to come. So it was with all of Pete's life.

Probably the greatest legacy left by Pete is his family, which is imbued with the same love for nature and preservation of the environment that epitomized Pete's life. We who knew and loved Pete can pay tribute to him by reflecting upon words he knew and lived by.

EARTH PRAYER

by Chief Seattle

This earth we know.
The earth does not belong to us;
we belong to the earth.
This we know.
All things are connected
like the blood which unites one family.
All things are connected.

—W. D. Sevon

E. I. Du Pont de Nemours and Company on the Wapwallopen:

GEOLOGY AND INDUSTRIALIZATION OF THE "POWDER HOLE"

by Jon D. Inners, Pennsylvania Geological Survey;
Duane D. Braun, Bloomsburg University;
Robert A. Janosov, Luzerne County Community College; and
David S. Miller, The Johns Hopkins University

INTRODUCTION. William Silver had a knack for applied geology. He demonstrated that knack in the mid-1850's, when he chose the lower end of the Wapwallopen Creek valley in southwestern Luzerne County as the site for his new water-powered powder works (Figure 1). Here, confined for 2 miles within a narrow valley 200 to 300 feet deep, the Wapwallopen drops a total of 210 feet and cascades over three falls, each more than 25 feet high. Below the Lower and Middle Falls, relatively flat, wooded floodplains of sufficient width to accommodate large buildings extend for long distances downstream. At various places along the valley sides are outcrops of hard gray and greenish-gray

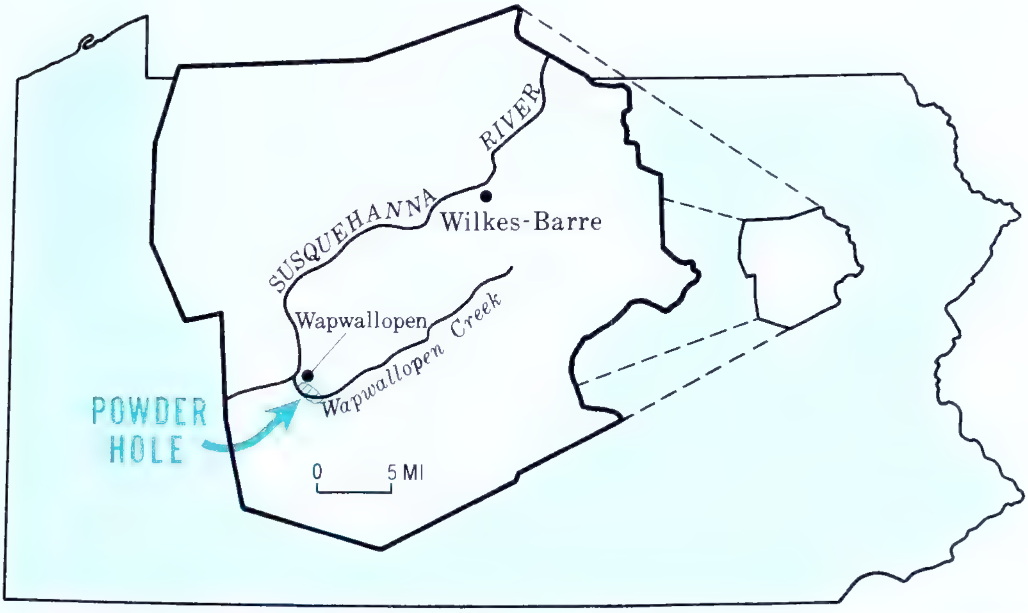

Figure 1. Location of the Powder Hole on Wapwallopen Creek in southwestern Luzerne County.

rock, ideal for rough dimension stone. And on the opposite bank of the North Branch Susquehanna lay the North Branch Canal (completed in 1831) and the Lackawanna and Bloomsburg Railroad (completed in 1856), vital lifelines for an operation dependent on the import of raw materials (especially saltpeter and sulfur) and the export of a finished product to market.

Silver erected a mill at the Lower Falls in 1856, soon selling part ownership to G. P. Parrish of Wilkes-Barre. Unfortunately, the same landscape features that made the lower Wapwallopen a perfect site for a water-powered mill rendered it prone to devastating floods. Early in 1859, a freshet (and a subsequent explosion) wreaked havoc in the gorge (Miller, 1979). The Silver-Parrish company went bankrupt, and E. I. Du Pont de Nemours and Company, a firm with far more capital and experience, bought the site in April of that year. Herein lies our story, for the rock outcroppings, waterfalls, and gaunt ruins along the lower Wapwallopen are a compelling reminder of the geologic factors that can significantly influence industrial development.

GEOLOGY OF THE "POWDER HOLE." Figure 2 shows the geology at the Wapwallopen site. (A few of the more important industrial features are also indicated on the map.)

The bedrock foundation of the area consists of two rock units of Late Devonian age, dating from about 380 million years ago when the Catskill delta built out into the Appalachian seaway. The Trimmers Rock Formation, which underlies the northern three fourths of the area, is a wholly marine sequence of gray siltstone, shale, and sandstone. Relatively coarser beds in this unit cap the Lower Falls (cover photograph). The Irish Valley Member of the Catskill Formation in the southern part of the Powder Hole consists of interbedded greenish-gray marine sandstones, siltstones, and shales and grayish-red nonmarine claystones. Thick-bedded sandstones and siltstones in the Irish Valley form the caprock of the Middle and Upper Falls. Throughout the Powder Hole, well-defined bedding partings dip to the southeast (Figure 2). Steeply inclined, planar fractures (joints) spaced 6 inches to several feet apart also transect most outcrops. The blocks formed by the intersection of these joints with bedding partings facilitated removal of stone from the several quarries opened in the walls of the gorge. At the northern end of the site, however, a zone of closely spaced, north-dipping fracture cleavage makes some of the lower beds of the Trimmers Rock unusable for building stone (see Figure 2). A precursor of today's Wapwallopen Creek probably began eroding a valley in these bedded, jointed, and cleaved rocks several million years ago.

The geologic event that most directly lead to the industrial development of the Powder Hole was the filling of the original valley

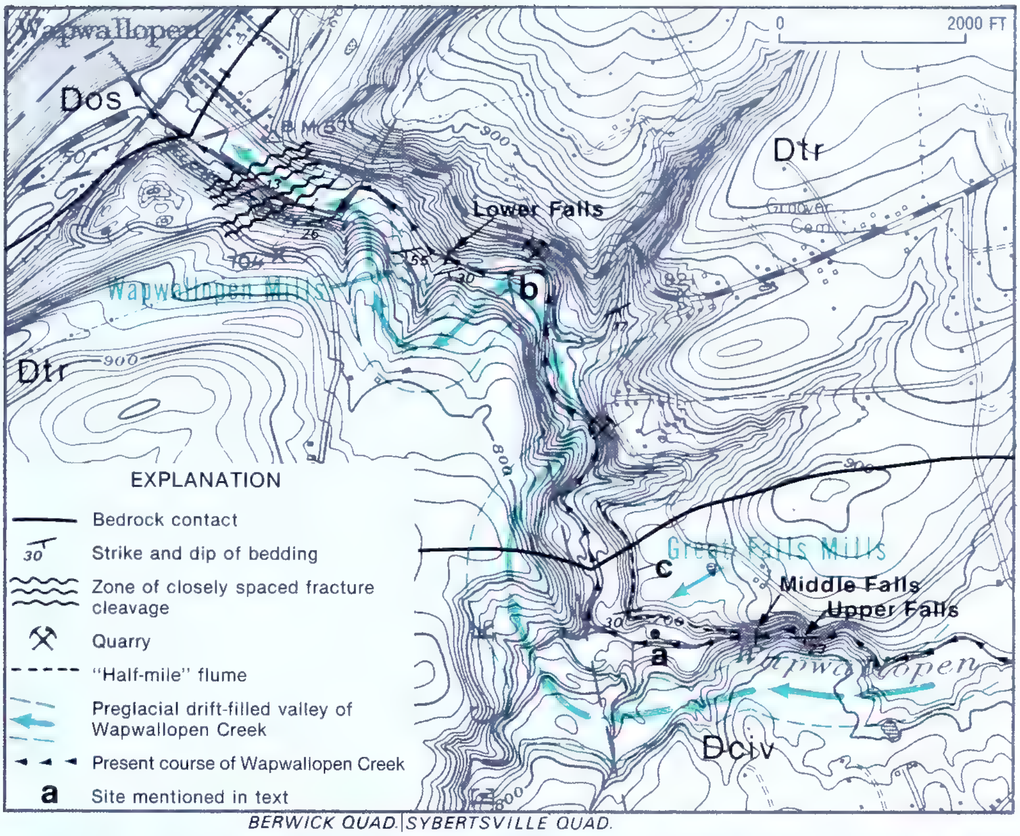

Figure 2. General geology of the Powder Hole area (after Inners, 1978, and Stratman, 1984). Dciv, Irish Valley Member of Catskill Formation; Dtr, Trimmers Rock Formation; Dos, older shales.

of Wapwallopen Creek with glacial deposits (Figure 2). This occurred about 20,000 years ago, when for approximately 1,000 years, the last Pleistocene ice sheet covered the Wapwallopen area (Crowl and Sevon, 1980; Braun, 1988). The glacial infilling (Stratman, 1984) started with sand and clay strata deposited in a lake dammed by the advancing glacier. Then sand and gravel were deposited by meltwater flowing from the glacier. Finally, the glacier overrode the site and deposited glacial till.

Retreat of the glacier from the area allowed water from the Wapwallopen drainage basin to start cutting a new valley in this plug of glacial sediment. Along most of its 25-mile length, the creek downcut through glacial material and reoccupied its old preglacial valley. But at several places in the Powder Hole area, the Wapwallopen missed its preglacial course and cut into bedrock to form precipitous waterfalls and nearly impassable gorges (cover photograph and Figure 2). Centuries later, these falls and steep declivities in the stream course supplied the water power necessary to run the Silver-Parrish and Du Pont mills.

THE MANUFACTURE OF BLACK POWDER. Black powder is a mixture of saltpeter, sulfur, and charcoal in approximate proportions of 6:1:1. (True saltpeter is potassium nitrate, but the term also includes sodium nitrate.) The process used at Wapwallopen was basically the one taught to Eleuthere Irenee du Pont, founder of the company, by the great French chemist Antoine Lavoisier in the 1780's. It is summarized in Figure 3. Potassium nitrate (used in the first four years of operations at Wapwallopen) (Miller, 1979) was obtained from India; sodium nitrate (cheaper and just as effective for blasting powder) from Chile; and sulfur mainly from Sicily. Charcoal was made by "distilling" deciduous wood, preferably willow, at the plant site (see Wilkerson, 1966).

From an archeological standpoint, two of the important precepts of Lavoisier's method were that the various steps in the manufacturing process be isolated in widely spaced buildings and that the buildings themselves be constructed in such a way as to direct the force of any accidental explosions upward and in a single (relatively harmless) lateral direction (Carr, 1964). The entire Powder Hole complex, with its more than 50 buildings scattered along nearly 2 miles of creek bottom, clearly illustrates the first of these rules, and the massive, three-sided ruin of the rolling, or twin, mill at the Great Falls mills (a on Figure 2) exemplifies the second.

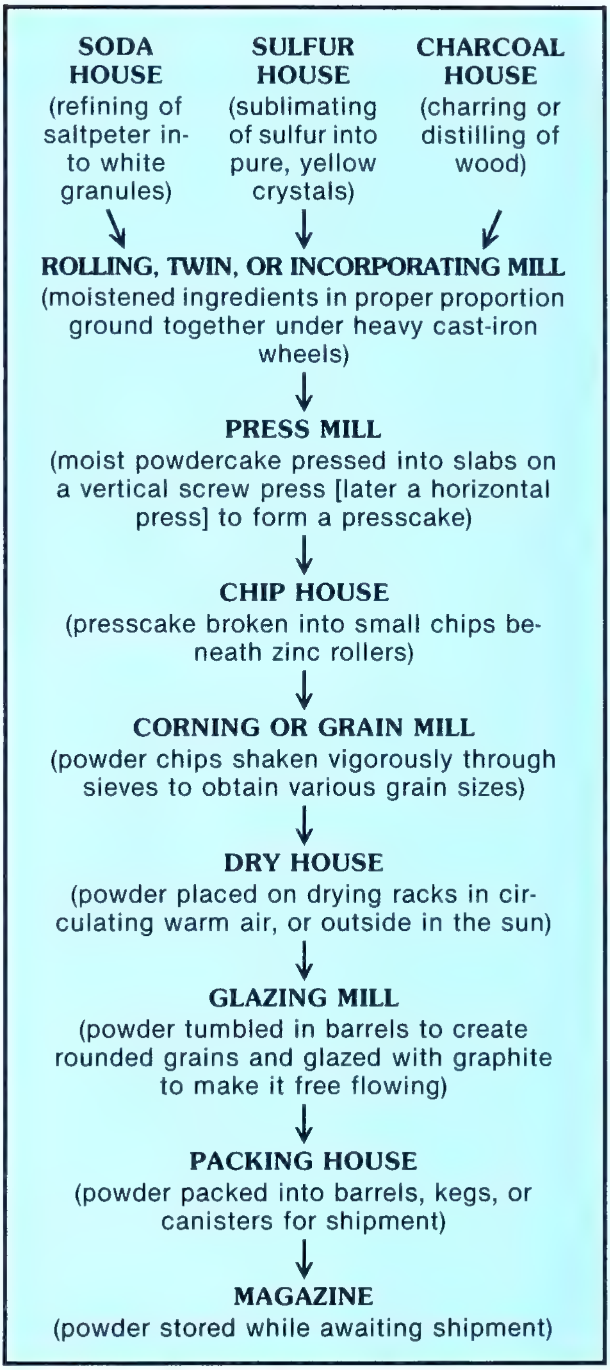
SODA HOUSE
(refining of saltpeter into white granules)
SULFUR HOUSE
(sublimating of sulfur into pure, yellow crystals)
CHARCOAL HOUSE
(charring or distilling of wood)
ROLLING, TWIN, OR INCORPORATING MILL
(moistened ingredients in proper proportion ground together under heavy cast-iron wheels)
PRESS MILL
(moist powdercake pressed into slabs on a vertical screw press [later a horizontal press] to form a presscake)
CHIP HOUSE
(presscake broken into small chips beneath zinc rollers)
CORNING OR GRAIN MILL
(powder chips shaken vigorously through sieves to obtain various grain sizes)
DRY HOUSE
(powder placed on drying racks in circulating warm air, or outside in the sun)
GLAZING MILL
(powder tumbled in barrels to create rounded grains and glazed with graphite to make it free flowing)
PACKING HOUSE
(powder packed into barrels, kegs, or canisters for shipment)
MAGAZINE
(powder stored while awaiting shipment)

Figure 3. Steps in the manufacture of black powder at the Du Pont mills on the Wapwallopen.

HISTORY AND ARCHEOLOGY OF THE DU PONT POWDER WORKS

For more than 50 years after it began manufacturing black powder, E. I. Du Pont de Nemours and Company confined its activities to the valley of Brandywine Creek near Wilmington, Delaware (Carr, 1964). But by the mid-1850's, the company realized that continued expansion depended on getting closer to the markets—and where better to start than in the burgeoning anthracite district of northeastern Pennsylvania (Van Gelder and Schlatter, 1927). Fortuitously, the failure of the early operations on the Wapwallopen occurred soon after Lammot Du Pont, grandson of the founder, had invented a new and cheaper method of manufacturing an effective blasting powder (Wilkerson, 1984). With these incentives, the Du Ponts set to work rebuilding the old Silver-Parrish powder works.

Du Pont operations on the Wapwallopen lasted from 1859 to 1912. Important milestones (Bloss, 1976a, 1976b; Miller, 1979) were the opening of the Wapwallopen mills at the Lower Falls in July of 1859; the change from potassium nitrate to sodium nitrate in April of 1863; construction of the Great Falls mills below the Middle Falls in 1869; and the closing of the combined Wapwallopen-Great Falls mills in 1912. During these 50 years, fatal explosions ripped through the powder works about once every 8 years (Bloss, 1976a), and floods destroyed roads, dams, and flumes on numerous occasions (see Miller, 1979).

Eighty years after the demise of the Du Pont mills, ruins of nearly all of the industrial buildings constructed of the local bedrock and traces of many ancillary structures can still be seen at the Powder Hole (Janosov and Inners, 1991). Most impressive of the building ruins are those of the sulfur house (Figure 4) and power house at the Wapwallopen mills and the rolling mill at the Great Falls mills. Abandoned grades of an extensive network of railroads and carriage roads line both sides of Wapwallopen Creek, and linear excavations for the power flumes are clearly evident below the Lower Falls (cover photograph), on the triangular-shaped flat above the Lower Falls (**b** on Figure 2), and

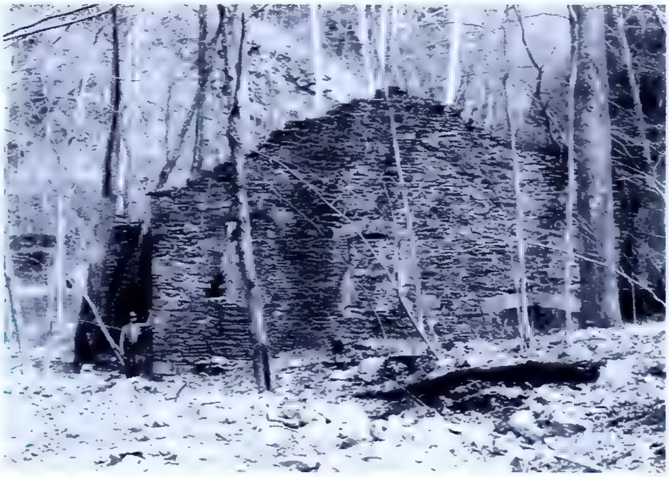

Figure 4. West wall of the sulfur house at the Wapwallopen mills. The rubbly gravel in the left foreground is part of a debris fan that issues from a big hollow to the west and probably dates from tropical storm Agnes in 1972. The nose of an older heavily vegetated fan is to the right.

on the steep slope downstream from the Middle Falls (the great "half-mile flume") (**c** on Figure 2). But floods, landslides, debris flows (Figure 4), and other processes of erosion and mass wasting are gradually taking a toll at the Powder Hole (Janosov and Inners, 1991). As more is lost with each passing year, accurate documentation of this most interesting industrial site will become increasingly difficult.

CONCLUSION. What are the lessons to be learned from the rocks and ruins at the Powder Hole? One is certainly that the causes of industrial development cannot be divorced from geologic history. The powder works on the Wapwallopen came into existence in large part because a series of events taking place over millions of years culminated in geographic conditions favorable to sustaining an industry dependent on water power. Blasting powder rather than some other product was manufactured at the Powder Hole because of the readily available markets in the nearby anthracite fields. A second lesson is that history is as much contingency as cause-and-effect (Gould, 1989). For if the Wapwallopen valley had not been so completely buried by glacial drift, the postglacial stream would have simply reoccupied its previous course and cleaned out the original broad, gently sloped valley. Then there would have been few rock outcroppings and no falls, no water power, and no powder mills on Wapwallopen Creek.

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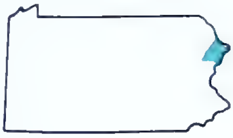
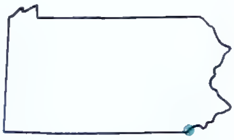
NEW PUBLICATIONS

Geology and Mineral Resources of Pike County



Geology and Mineral Resources of Pike County, Pennsylvania has been published by the Pennsylvania Geological Survey. This report contains detailed descriptions of the surficial and bedrock geology, discussions of the geologic history, and evaluations of the mineral resources of Pennsylvania's fastest growing county, which had a population increase of 99.5 percent from 1960 to 1980. County Report 52, by W. D. Sevon, Thomas M. Berg, Lane D. Schultz, and the late George H. Crowl, consists of a 141-page book and bedrock and surficial geologic maps at a scale of 1:50,000. It is available for $22.50, plus 6 percent state sales tax for Pennsylvania residents, from the State Book Store, 1825 Stanley Drive, Harrisburg, PA 17103. Orders must be prepaid; please make checks payable to *Commonwealth of Pennsylvania*.

Guide to White Clay Creek Preserve



The Pennsylvania Geological Survey has prepared and published Park Guide 20, **White Clay Creek Preserve, Chester County, Pennsylvania; New Castle County, Delaware—A Scenic Valley and the Arc Corner**, by Rodger T. Faill, in cooperation with the Pennsylvania Bureau of State Parks, the Delaware Geological Survey, and the Delaware Department of Natural Resources and Environmental Control, Division of Parks and Recreation. Part of the Trail of Geology series, this 12-page booklet is designed to make a visit to the Preserve more interesting, educational, and understandable to the general public. Brief discussions of the early settlement of the area, the unique (and at one time controversial) arcuate boundary between Pennsylvania and Delaware, and the creation of the Preserve complement the geologic discussions of the history of the metamorphic rocks and White Clay Creek valley. Park Guide 20 is available at no charge from the park office at White Clay Creek Preserve or from the Pennsylvania Geological Survey, P. O. Box 2357, Harrisburg, PA 17105-2357, telephone 717-787-2169.

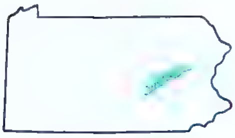
Rocks and Minerals of Pennsylvania

For many years, Educational Series 1, *Common Rocks and Minerals of Pennsylvania*, was among the more popular publications of the Pennsylvania Geological Survey. First published in 1962, ES 1 was recently rewritten by John H. Barnes and published as **Rocks and Minerals of Pennsylvania**. This 30-page, heavily illustrated booklet includes discussions of basic concepts of petrology and mineralogy and how these apply to the formation of rock types that are found in Pennsylvania. Emphasis is placed on the lithologic cycle as a form of natural recycling. Practical applications of rocks and minerals in everyday life are also discussed. The booklet is aimed at students at the middle-school level and at inquiring adults. It may be obtained free of charge from the Pennsylvania Geological Survey, P. O. Box 2357, Harrisburg, PA 17105–2357, telephone 717–787–2169.

Geology and Mineral Resources of the Blandburg, Tipton, Altoona, and Bellwood Quadrangles

The Pennsylvania Geological Survey announces the availability of a new publication, **Geology and Mineral Resources of the Blandburg, Tipton, Altoona, and Bellwood Quadrangles, Blair, Cambria, Clearfield, and Centre Counties, Pennsylvania**. This report contains detailed descriptions of the bedrock and surficial geology, discussions of the geologic history, and evaluations of the mineral resources of the region, including coal, stone, metallic minerals, and gas. The report consists of a 209-page book and 10 plates. Among the plates are a bedrock geologic map and cross section at a scale of 1:24,000, a 1:48,000-scale map of surficial geology, logs of drill holes, and six 1:48,000-scale resource maps showing the thickness, crop lines, and extent of known mining of major coal beds. Atlas 86, by Rodger T. Faill and Albert D. Glover of the Pennsylvania Geological Survey and John H. Way of Lock Haven University, is available for $35.00, plus 6 percent state sales tax for Pennsylvania residents, from the State Book Store, 1825 Stanley Drive, Harrisburg, PA 17103. Orders must be prepaid; please make checks payable to *Commonwealth of Pennsylvania*.

Groundwater Resources in and near the Anthracite Basins of Schuylkill and Adjacent Counties



The latest in the Pennsylvania Geological Survey's series of Water Resource Reports, **Groundwater Resources in and near the Anthracite Basins of Schuylkill and Adjacent Counties, Pennsylvania**, has recently been published. It was prepared by Albert E. Becher of the U.S. Geological Survey as a part of the continuing cooperative effort of the State and Federal Surveys to study and evaluate the groundwater resources of the Commonwealth. This report contains descriptions of the flow systems and quality of groundwater in an area in which these characteristics have been greatly modified by anthracite mining. The 59-page book includes extensive tables of water-quality measurements, well records, and other data. Water Resource Report 64 is available for $11.75, plus 6 percent state sales tax for Pennsylvania residents, from the State Book Store, 1825 Stanley Drive, Harrisburg, PA 17103. Orders must be prepaid; please make checks payable to *Commonwealth of Pennsylvania*.

Indiana County Coal Maps on Open File

A new open-file report, **Coal Resources of Indiana County, Pennsylvania—Part 1, Coal Crop Lines, Mined-Out Areas, and Structure Contours**, is available for inspection at the Pennsylvania Geological Survey. Two types of maps are presented for each 7.5-minute quadrangle in Indiana County. One map for each of the principal coal seams shows the outcrop pattern, or crop line, and the extent of known mining of the seam. One additional map per quadrangle shows the outcrop patterns of all major coal seams, structure contours, and fold axes. Of use to environmental-protection specialists and land use planners as well as those in the coal industry, this report by William A. Bragonier of the Rochester and Pittsburgh Coal Company and Albert D. Glover of the Pennsylvania Geological Survey can be seen at 101 South Second Street, Room 912, in Harrisburg. Please telephone Albert D. Glover, 717-787-6029, for more information.

BENEDUM HALL—A CELEBRATION OF GEOLOGY

by John A. Harper, Pennsylvania Geological Survey; and
Mary R. Dawson, Carnegie Museum of Natural History

In October 1988, the Carnegie Museum of Natural History in Pittsburgh opened its new Benedum "Hall of Geology." Benedum Hall is a celebration of geology, an enticing and visually stimulating place to visit and study. It is, above all, a tribute to the vital role that Pennsylvania has had, and continues to have, in the history of geology and the development of geological concepts.

Pennsylvania's claim to fame in the annals of earth science is second to none. No geology textbook is complete without a detailed recounting of the complex history of the formation of the Appalachian Mountains, which curve through the central part of the state. No history of economic geology is sufficient without the story of Drake's oil well, drilled in 1859 near Titusville in Crawford County. This famous well marked the beginning of the world's oil industry. By the same token, the story of economic geology would not be complete without mention of the role that Pennsylvania coals played in the nation's industrial development. Even the geologic time scale contains a tribute to the rocks of the state, for the interval between 286 and 320 million years ago bears the name "Pennsylvanian" in honor of the extraordinary occurrence of the sedimentary rocks of that age—the sandstones, shales, limestones, and coals—here in the Commonwealth (see also "A Missed Centennial" on page 16 of this issue).

When the staff of the Carnegie Museum began to plan the construction of a new geology hall, they faced the challenge of using the familiar rocks and geologic structures that are common parts of the Pennsylvania landscape to present the most modern ideas and details of the earth sciences. With that challenge in mind, the Museum acquired funding from the Philip M. McKenna Foundation and the Claude Worthington Benedum Foundation to begin the project. Carnegie Museum employed Gerard Hilferty and Associates, an exhibit design firm of Athens, Ohio, to design a geology display that would be entertaining, educational, and, above all, visually captivating. The design that Gerard Hilferty and Associates created was eventually brought to life by Visual Communications Inc. of Philadelphia. The design is based on a series of hemispherical domes that represent the earth as seen from space. Where the domes are sectioned to house the exhibits, the cut surfaces depict rock strata. Each of the four domes in Benedum Hall has a theme: geologic time and age dating; plate tectonics and the forces that shaped the rock record; fossils and fossilization; and geologic highlights of the Pittsburgh area. Other exhibits outside the domes complement these themes.

In the first dome, the principles of geochronology are illustrated, including the dating of rocks using fossils and radioisotopes. An interactive computer workstation allows visitors to test their knowledge of geologic dating by determining the ages of several rock specimens on display. Nearby is the "Time Tower" (Figure 1), a tall cylinder decorated with 4,600 lights that spiral upward from the base as the story of the earth's history is narrated. Each light represents 1 million years of geologic time; large globe lights representing the more important "dates" in earth history punctuate the spiral.

The dome housing the plate-tectonics display includes a video theater that introduces visitors to the concept of the restless earth and a model showing the deformation of the North American and African crustal plates during crustal collisions. In the video display,

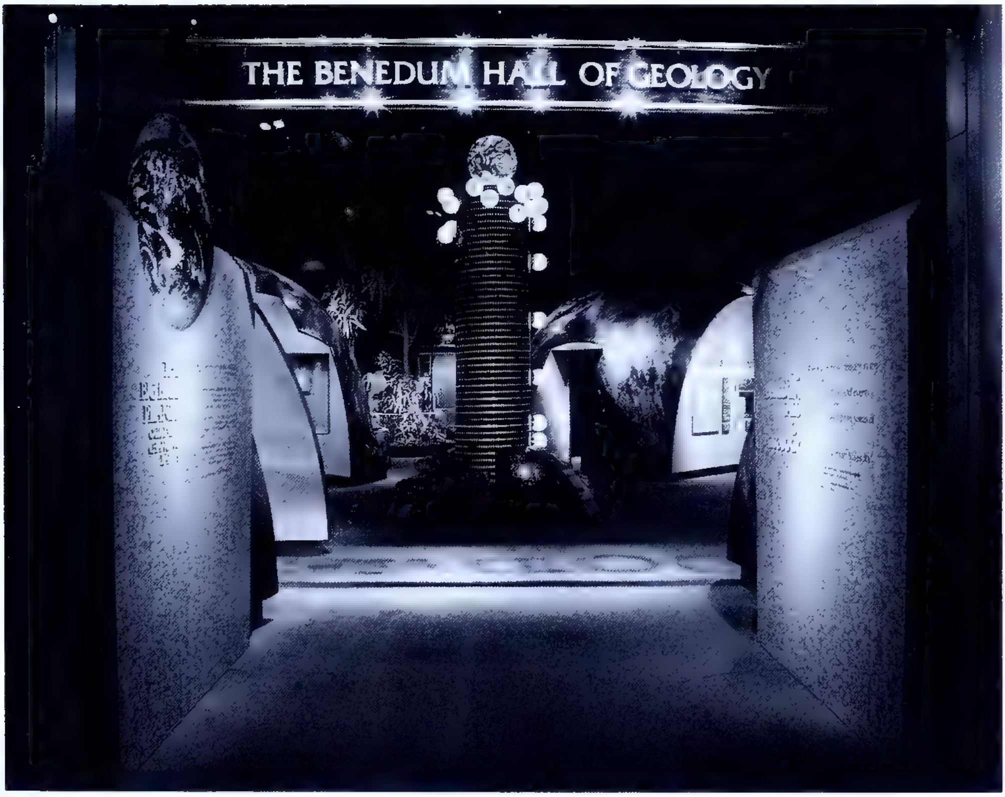


Figure 1. The Time Tower at the entrance to Benedum Hall. Photograph courtesy of Girard Hilferty and Associates.

the Pittsburgh area is used as an example of a piece of the earth that has undergone drastic changes, and visitors are challenged on their knowledge of Pittsburgh's geologic past. The "Mountain Builder" is an active model that allows the visitor to create the Appalachian Mountains by turning a wheel that drives Africa and North America into collision. The exhibit shows how at least three intervals of plate interactions occurred during the Paleozoic Era. Each interaction created mountains that were eventually eroded, shedding great quantities of sediment into adjacent seas. These sediments were, in turn, uplifted, deformed, and eroded by later mountain-building events.

A third dome is dominated by fossils (Figure 2). The exhibit shows how these remains of past life were formed, what they indicate about life in the past, and what they tell us about ancient geography and climate. Visitors are challenged to test their understanding of ancient life by trying to determine what is a fossil and what is a pseudofossil in an interactive quiz. Nearby displays include previously existing dioramas of a Pennsylvanian sea floor and a coal-age swamp. The swamp diorama, a Carnegie Museum favorite for near-

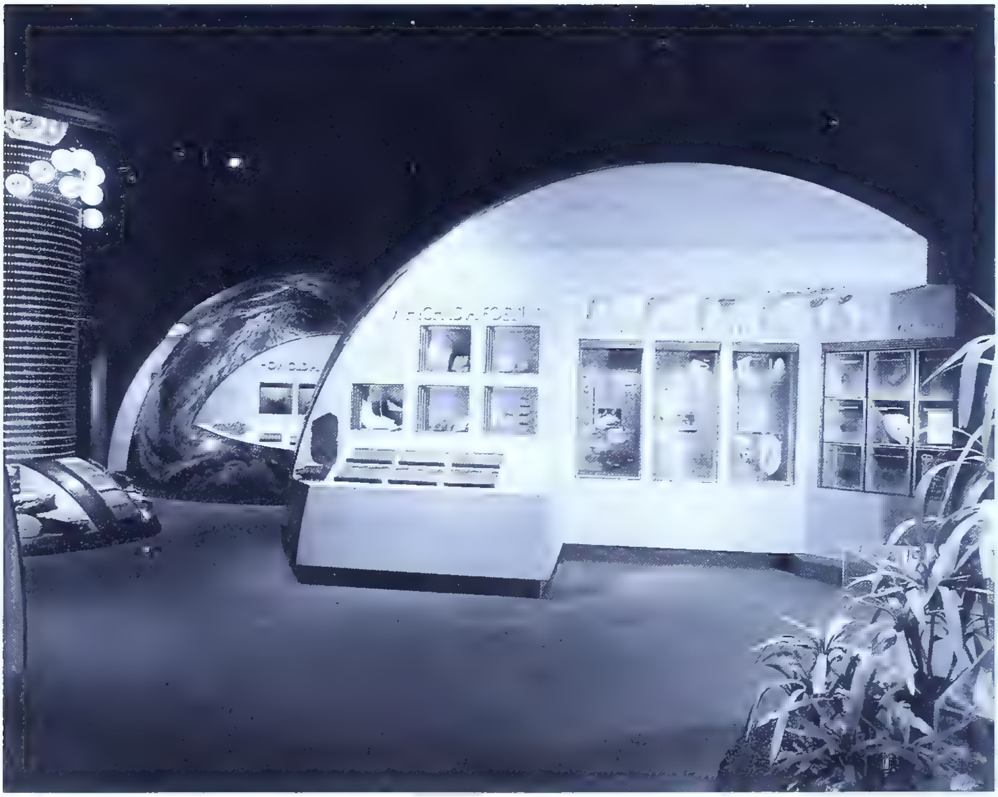


Figure 2. Fossils are a prominent part of the display in Benedum Hall. Photograph courtesy of Visual Communications Inc.

ly 50 years, received a facelift for the exhibit; the plants and animals were cleaned, and new plants and animals were added to expand the scene out into the exhibit hall. The new part will not be behind glass, so visitors can get a close-up view of what much of Pennsylvania looked like 300 million years ago. A novel exhibit, containing actual living relatives of the Paleozoic scouring rushes, cycads, and other plants, provides a nice continuity between past and present.

A close look at the geology of the Pittsburgh area is provided by the fourth dome. An interactive video exhibit displays various areas in southwestern Pennsylvania on command, illustrating rock formations and fossil-collecting localities. Coal, oil, and natural gas, the fossil fuels that have contributed so much to the economic importance of western Pennsylvania, are highlighted in a display on economic geology. Examples of bituminous and anthracite coals, and various Pennsylvania Grade crude oils, are exhibited along with explanations of their origins and how they are extracted. The "Stratavator" is a truly unique exhibit, offering the educational advantages of a video display and the excitement of an amusement park ride. This exhibit is a simulated elevator ride, complete with a moving cab that gives a remarkably eerie sensation of vertical movement to a depth of 16,000 feet beneath the floor of Benedum Hall. Upon entering the cab of the "Stratavator," visitors meet their tour guide, a miner appropriately named Rocky, seen through the cab's "window" (a video screen). The ride stops at several formations, ending at the metamorphic rocks of the crystalline basement. Between stops, the intervening rock strata whiz by the "window" while a counter measures the depth and the geologic age of the passing rocks.

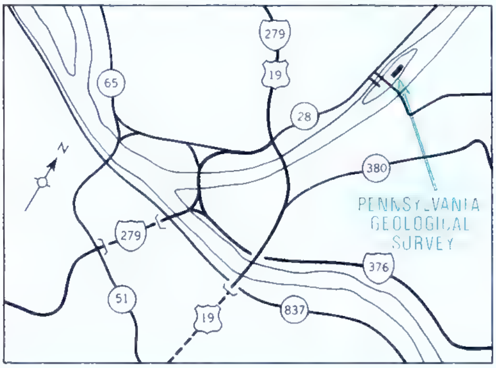
Pennsylvania's complex geology is recorded in the geologic map, a visually outstanding exhibit that dominates the south wall of the hall. The map is a photographically enlarged version of the *Geologic Map of Pennsylvania* that has been mounted on a large block. The original map, donated by the Pennsylvania Geological Survey, included a set of cross sections on a separate sheet; in the enlarged reproduction, the map and block have been cut along the lines of these sections and the cross sections mounted on the sides of the block to show the three-dimensional aspects of Pennsylvania geology.

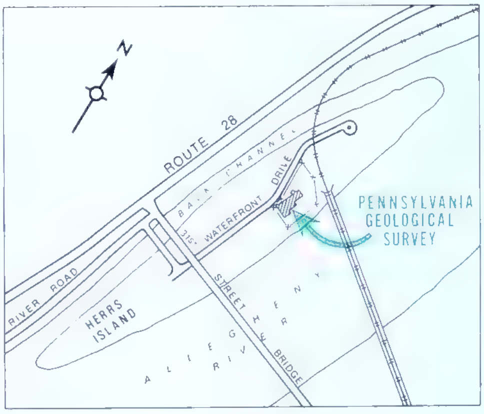
The creation of Benedum Hall was an interdisciplinary effort on the part of many people from the Carnegie Museum, academia, industry, and the Pennsylvania Geological Survey. Besides donating the use of the originals of the *Geologic Map of Pennsylvania*, the Survey also provided display samples and technical advice. Readers are encouraged to visit the Benedum Hall of Geology while in the Pittsburgh area. Earth science teachers will find Benedum Hall a worthwhile teaching aid and a great place for field trips.

ANNOUNCEMENTS

Oil and Gas Geology Division Moves

The Pennsylvania Geological Survey's Oil and Gas Geology Division, which is based in Pittsburgh, moved in December 1991 to Washington's Landing, on Herrs Island in the Allegheny River. The move was the first of a two-part move for the division, which is currently in temporary quarters. The second part of the move is scheduled for late summer, following the construction of the building across the street that is to serve as the division's permanent home. The relocation to Washington's Landing is expected to result in improved integration with other programs of the Department of Environmental Resources, which are also moving to this site. The new address is 400 Waterfront Drive, Pittsburgh, PA 15222-4745. The telephone number is 412-442-4235 (636-4235 on the State network). Washington's Landing is conveniently located about 1 mile from Interstate 279. Access to the island is provided via a bridge off River Avenue near Pa. Route 28 and 31st Street. Visitors will find ample free parking.





A Missed Centennial

An event that was unannounced during the past year was the centennial of the naming of the Pennsylvanian Period of geologic time. In 1891, our Commonwealth was honored in geological literature by being chosen as the namesake for the portion of geologic time from 320 to 286 million years ago, during which the major deposits of coal were formed in North America. The hundredth year of the use of our state's name passed unnoticed by but a few. How many readers remembered or thought of the distance that Pennsylvania has traveled in the 286 million plus 100 years since the end of the Pennsylvanian Period, when the land that is now Pennsylvania was south of the equator?

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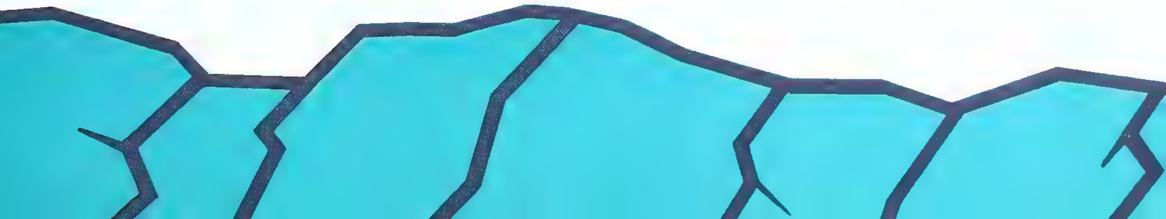
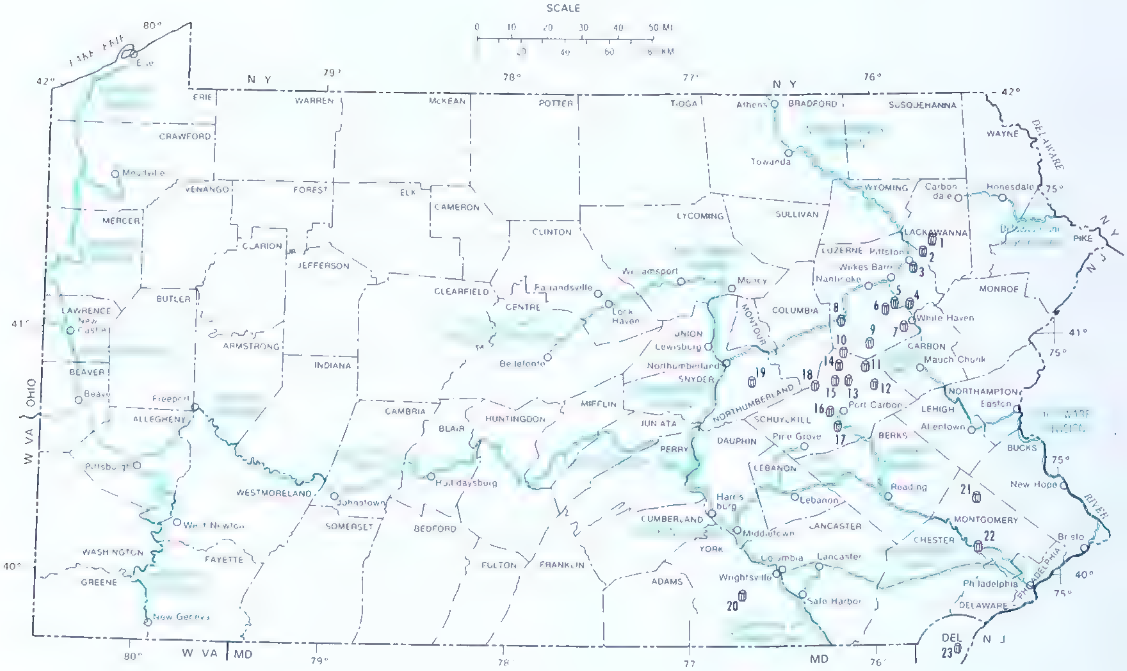
IN COOPERATION WITH THE U.S. GEOLOGICAL SURVEY

TOPOGRAPHIC MAPPING
GROUNDWATER-RESOURCE MAPPING



PENNSYLVANIA CANAL SYSTEM, 1855

(See article on page 2)



EXPLANATION

Canal

Navigable river

Railroad

19 Black-powder works

See list at right for names of localities corresponding to numbers on map.

1	Scranton	13	Mahanoy City
2	Moosic	14	Brandonville
3	Pittston	15	Shenandoah
4	Laurel Run	16	Pottsville
5	Georgetown	17	Cressona
6	Mountaintop	18	Ashland
7	White Haven	19	Shamokin
8	WAPWALLOPEN	20	York
9	Hazleton	21	Sumneytown
10	Nuremberg	22	Norristown
11	Quakake	23	Wilmington, Delaware (original Du Pont mills)
12	Tamaqua		

SOURCES. Baer, C. T. (1981), *Canals and railroads of the Mid-Atlantic States, 1800-1860,* Regional Economic History Research Center, Eleutherian Mills-Hagley Foundation, [80 p.]; Chandler, A. D., Jr., and Salsbury, Stephen (1971), *Pierre S. du Pont and the making of the modern corporation,* New York, Harper and Row, 722 p.; Shank, W. H. (1973), *The amazing Pennsylvania Canals,* 3rd edition, York, Pa., American Canal and Transportation Center, 80 p.; Van Gelder, A. P., and Schlatter, Hugo (1927), *History of the explosives industry in America,* New York, Columbia University Press, 1,132 p.

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ON THE COVER

Planar crossbedding in the Loyalhanna Formation in the bluestone quarry at Linn Run State Park, Westmoreland County. The tree trunk on the right side of the photograph is approximately 10 inches in diameter. Photograph by William E. Kochanov.

PENNSYLVANIA GEOLOGY

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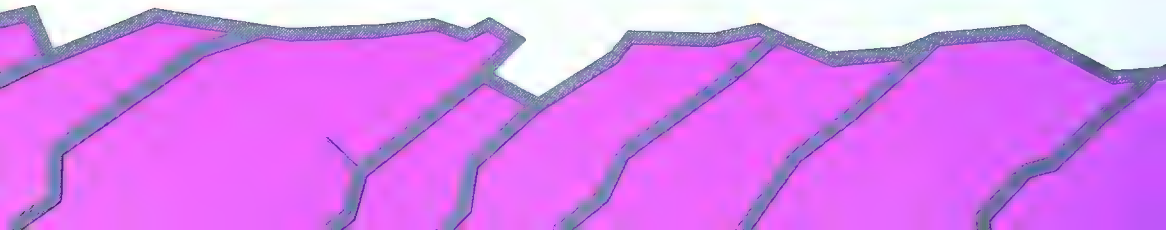

STATE GEOLOGIST'S EDITORIAL

The Intrusion of Nature on Humanity and Vice Versa

In an article in the *Washington Post* (March 15, 1992), Richard Cohen wrote about the "perversity of nature," citing as an example "an awful drought." In the past year, many areas of our nation, including parts of Pennsylvania, experienced a period of water shortage because of below normal rainfall. This circumstance at times forced individuals, public water suppliers, and Pennsylvania water resource management agencies to impose personal or public restrictions on water use. Once again, nature, in the form of a drought, has intruded on human events; a "perversity" to Mr. Cohen and possibly some others. But to classify a drought (or any other natural event that negatively affects humans, such as the recent Hurricane Andrew) as perverse is a failure in understanding naturally occurring events. Although we sympathize with those who suffer from such events, to suggest, as does Mr. Cohen, that there is a "perversity of nature" is, in a sense, to ascribe to nature an ability to consciously inflict benefit or harm on humanity. That is not our present understanding of nature. Circumstances that impact humanity such as sinkhole collapse, landslides, earthquakes, volcanic eruptions, and global climatic change (including droughts) are natural events that have repeatedly occurred throughout geologic time and will continue to do so as dynamic earth systems fluctuate in response to the energy of the system at a particular time.

Any "perversity" that can be attached to such natural events comes not from the natural events but from human lack of understanding and occasional hubris that refuses to acknowledge or accept the predictable impacts of human intrusion into the earth's natural geologic and environmental systems. As humanity expands over the globe, we increasingly interact with natural systems. If we exceed the capacity of these systems, such as by overuse, *we*, not nature, cause harm. Unless we understand natural systems, we increasingly will be restricted by nature or we will damage the systems and thereby damage ourselves.

It is the responsibility of earth scientists to educate our public (and national writers) to the reality and importance of the earth's natural systems so that we can better understand, and through understanding, effectively plan how to operate in harmony with nature. Not to understand and plan is the true perversity.

Donald M. Hoskins

Donald M. Hoskins
State Geologist

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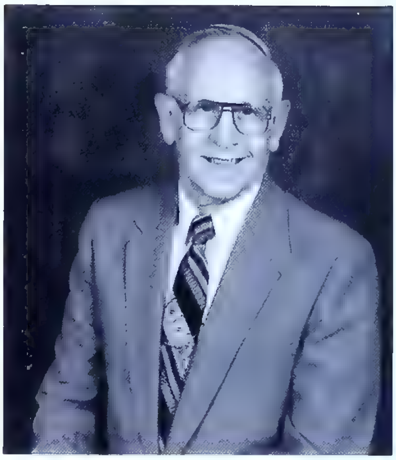
DOCUMENTS SECTION

IN MEMORIAM

William Stuckley Lytle

1915-1991

1933-1977 Pennsylvania Geological Survey



William Stuckley Lytle will be remembered for his love; his love of God, his love of family, his love of mankind, and his love of geology. He gave totally of himself and lived his life to the fullest.

Born in Pleasantville, just 6 miles from the site of the Drake oil well, Bill was destined to choose oil and gas as his career. One of four children, he helped his father pump family oil wells in Titusville during his high school years. He graduated from Pennsylvania State College in 1940 with a degree in petroleum and natural gas engineering. While in school, he worked as an assistant in the Pleasantville-Oil City area for the Bureau of Topographic and Geologic Survey during the summer. Upon graduation, he joined the staff full time.

For 34 years, until his retirement in 1977, Bill was the Survey's backbone in all matters relating to the Commonwealth's oil and gas resources. His only interruption in Survey service was a four-year tour of duty with the U.S. Army Corps of Engineers during World War II. After the war, he maintained active status in the Reserves for over 30 years and retired as a full colonel.

Bill spent much of his career mapping and writing about oil and gas. His published reports on Pennsylvania's crude oil reserves, oil and gas fields, and underground gas storage, his annual reviews of oil and gas developments in Pennsylvania from 1954 through 1976, and the field atlas of the Butler quadrangle still stand as basic references on these subjects. He had over 100 articles published in major oil and gas journals, and he presented well over twice that number of talks to professional societies in and out of the state.

Bill served on committees and was an officiary of numerous professional organizations, but he was equally proud of his service to his church, the public, and the community.

Bill is survived by his wife, Virginia Heath Lytle, a gifted writer and poet, and four talented children, all of whom he spoke of often and lovingly.

We will miss Bill, but a part of him lives on in each of us.

—Cheryl L. Cozart

THE GREAT PENNSYLVANIA EARTHQUAKE THAT NEVER WAS

by Charles K. Scharnberger
Department of Earth Sciences,
Millersville University

INTRODUCTION. There it was, right on the cover of the November 1990 issue of *Geotimes*: a map with a large red square in northeastern Pennsylvania indicating the epicenter of one of 10 "more significant" earthquakes to have occurred in the Eastern United States in historic times. In the accompanying article (Snider, 1990), the author discussed the earthquake hazard in the East and identified this event as "Wilkes-Barre, Pa., 1954, Magnitude 5.0." Six months later, *Geotimes* carried another map (Anonymous, 1991), "Damaging Earthquakes, 1534–1988," showing two supposed magnitude 5.0 earthquakes in Pennsylvania, one at Wilkes-Barre and the other in the central part of the state. (The latter "earthquake," almost certainly a quarry blast, is not further discussed here.)

The notion that a significant earthquake had occurred in Wilkes-Barre took hold almost immediately after the event itself in February 1954 and found its way into various earthquake catalogs (e.g., Murphy and Cloud, 1956; Dames and Moore, 1970; Conrad and Geyer, 1971; von Hake, 1976; Howell, 1979; Coffman and others, 1982; Stover and others, 1987). In these catalogs, an earthquake having a maximum intensity of VII on the Modified Mercalli Scale is listed for February 21, 1954, accompanied by a strong aftershock (maximum MMI VI) on February 23.

To be sure, some catalogs indicate a possible nontectonic origin for these events, and an investigation of seismic hazard at the site of the Susquehanna Steam Electric Station conducted by Weston Geophysical Research, Inc., for the Pennsylvania Power and Light Company concluded that no earthquakes had occurred (Pennsylvania Power and Light Company, 1975). I was aware from informal conversations with various seismologists in the Eastern United States that the best-informed opinion was that the Wilkes-Barre "earthquake" of 1954 was an instance of mine collapse, quite a common occurrence in both the anthracite and bituminous coal regions of Pennsylvania. Yet, in a conversation with Carl Stover, a seismologist with the U.S. Geological Survey, I learned that the U.S. Geological Survey, while aware of the mine-collapse theory, felt that no one had yet investigated the matter sufficiently to establish whether a significant earthquake had occurred in Wilkes-Barre. Thus, I decided to examine the event insofar as possible after 37 years had elapsed.

WHAT HAPPENED IN WILKES-BARRE IN LATE FEBRUARY 1954? Most of my research was done in the newspaper room of the State Library, where back issues of virtually every newspaper ever published in Pennsylvania are available on microfilm. There, through the pages of the *Wilkes-Barre Record*, I tried to understand what had happened in Wilkes-Barre that February. Here is a summary of what I learned.

At 2:50 p.m., EST, on Sunday the 21st, residents of a four-block area in what is known as the Old River Road section of Wilkes-Barre (about 1 mile west of the center of the city) were startled by a loud noise and a sudden jolt to their houses that caused windows to break and walls to crack. One resident described a sound "like hail hitting windows" that continued for about 5 minutes following the first noise (*Wilkes-Barre Record*, February 22, 1954). Outside, streets and driveways had buckled and sidewalks had heaved. One witness reported seeing a road buckle about 10 minutes after the first shock. News stories over the next several days make it clear that earth movements continued and damage accumulated gradually. More pavement was observed in the process of upheaving on Monday, February 22. A particularly large and sudden earth movement occurred the next day (the "aftershock" of many earthquake catalogs). A water main broke on the 24th and another on the 26th. Meanwhile, more upheavals were reported as having been observed on Thursday, the 25th (*Wilkes-Barre Record*, February 22–27, 1954). The affected area gradually increased beyond the initial four blocks. It is difficult to infer from the newspaper accounts the exact limits of the area that eventually was affected, but it seems to have been approximately as shown in Figure 1.

Speculation about the cause of these events naturally focused on the possibility of mine collapse, though spokespersons for the Glen Alden Coal Company firmly denied that their workings beneath the damaged area were in any way responsible. Some residents suggested that the earth movements could be related to a supposed former subterranean course of the Susquehanna River through the area. The possibility of an earthquake was suggested in the newspaper by a quoted remark from a citizen who compared what he had just experienced to what he remembered from San Francisco in 1906.

THE EARTHQUAKE MYTH. It is not completely clear how the interpretation of the Wilkes-Barre events as earthquakes came to be accepted. The *New York Times*, *Philadelphia Inquirer*, and *Philadelphia Evening Bulletin* of February 22 carried stories of "tremors" felt in Wilkes-Barre. It seems likely that the term "tremors" was chosen

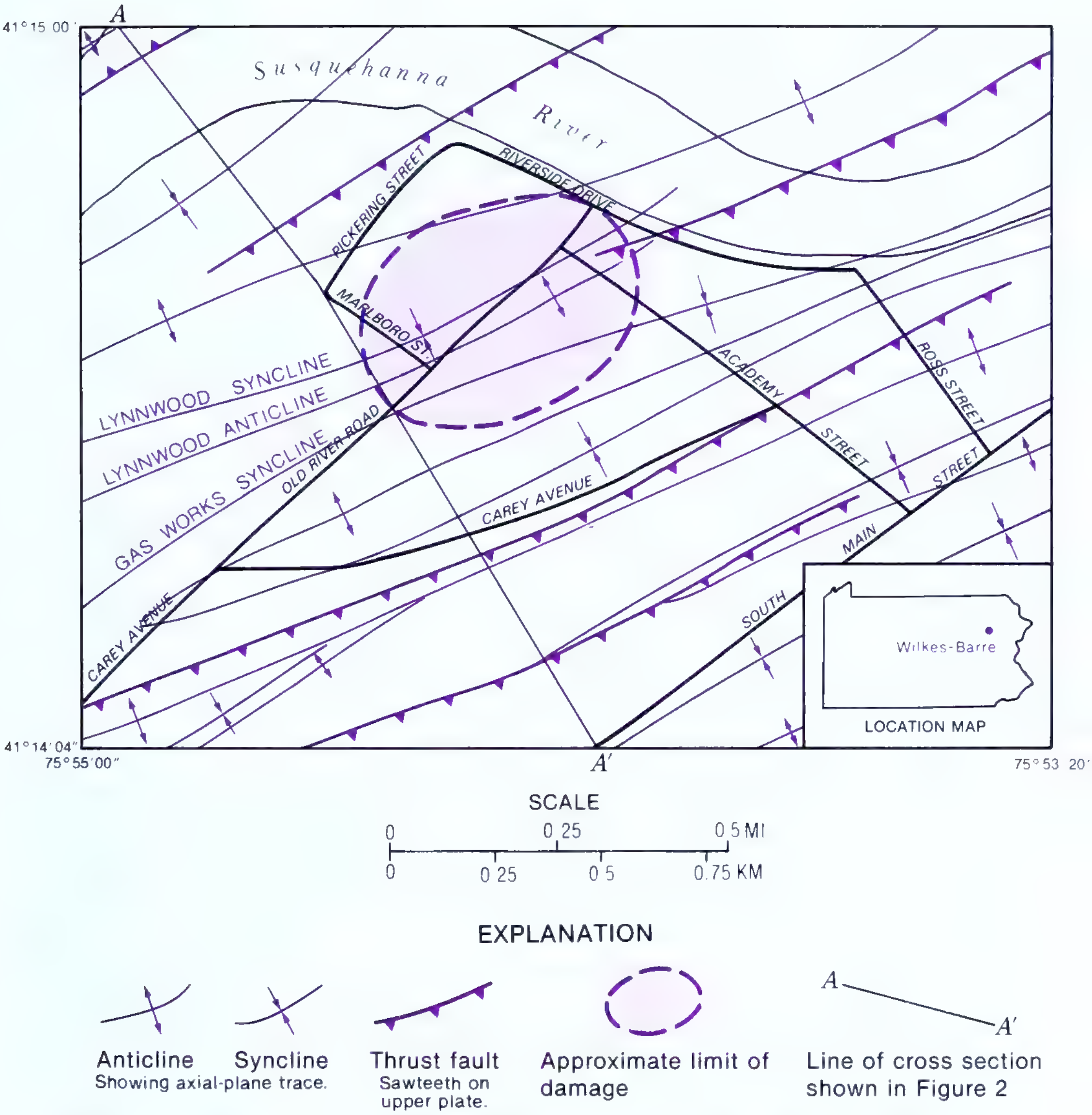


Figure 1. Map of part of Wilkes-Barre, Pennsylvania, showing the approximate limit of surface subsidence in February 1954 in relation to geologic structure in the Llewellyn Formation. Geology from Bergin (1976).

to be purely descriptive without implication as to cause. This term, however, frequently is used in connection with earthquakes and so may have helped plant the earthquake idea. In any case, by Thursday the 25th the impression that an earthquake had occurred in Wilkes-Barre was widespread, as indicated by a story in the *Wilkes-Barre Record* (February 26, 1954) about a local woman who had received a telephone call from her worried husband in Korea who had heard on Armed Forces radio about the serious earthquake back

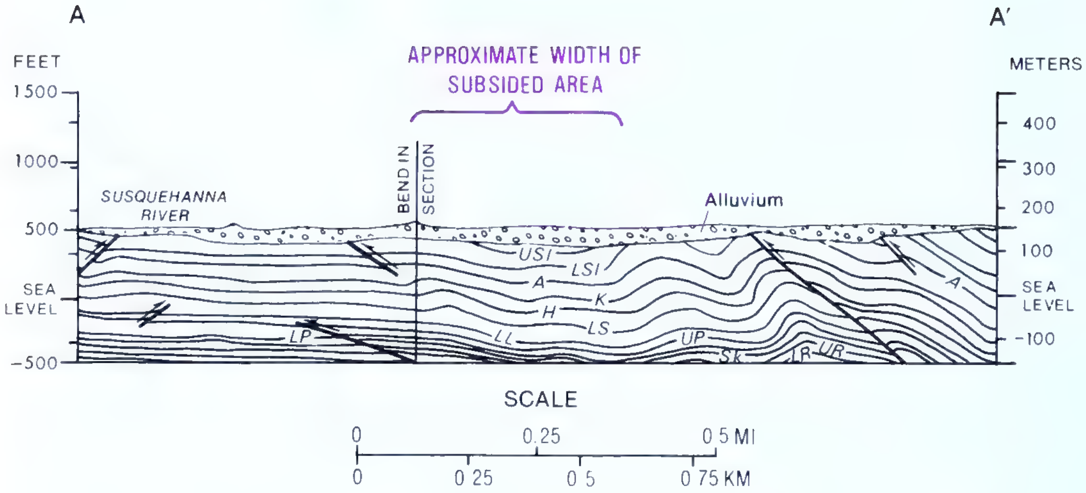


Figure 2. Structural cross section along line A–A′ of Figure 1, showing surficial deposits, major anthracite seams, and the relationship of the subsided area to geologic structure. The anthracite seams shown are as follows: USI, Upper Snake Island; LSI, Lower Snake Island; A, Abbott; K, Kidney; H, Hillman; LS, Lower Stanton; LL, Lower Lance; UP, Upper Pittston; LP, Lower Pittston; Sk, Skidmore; UR, Upper Ross; LR, Lower Ross. Geology from Bergin (1976).

home. It is interesting to note that the *Record* treated this story semihumorously, as it did a story about out-of-towners flocking to Wilkes-Barre to see the "earthquake damage." This suggests that folks in Wilkes-Barre did not think that they had experienced an earthquake, whatever "outsiders" might think.

If for no other reason, an earthquake explanation must be rejected because of the extremely small area over which the "tremors" were felt. Based on the damage inflicted, seismologists have assigned a maximum Modified Mercalli intensity of VII to this "earthquake." But if it really had been an earthquake, then we would expect a zone of intensity VI to have surrounded the zone of maximum intensity, a zone of intensity V to have surrounded that zone, and so forth. The total area over which such an earthquake was felt ought to have been several tens of thousands of square miles. In fact, nothing resembling this pattern of seismic intensity occurred in 1954.

Ironically, one of the factors that seems to have contributed to the earthquake myth was the very thing that should have quashed it: a seismologist's statement that no earthquake was recorded at or around 2:50 p.m. on February 21. The seismologist consulted by the media was Rev. Joseph Lynch of Fordham University. Fr. Lynch clearly stated that nothing was recorded on the Fordham seismograph at 2:50. However, he also mentioned that "shocks" were recorded at 11:19 a.m. and 6:45 p.m. (*Philadelphia Inquirer*, February 23, 1954). It may seem obvious to the seismologically minded that these events, whatever they were (the one at 11:19 was an earthquake in Alaska), were at the wrong times to explain what had happened in Wilkes-Barre, but that was not obvious to the reporters, who seemed impressed by the fact that something was recorded on the seismograph, regardless of the time. It did not help that the news story in the *Inquirer* reported that Fr. Lynch "would not say whether [the shocks] were in any way connected with the Wilkes-Barre tremors." There is a world of difference between "would not say whether" and "said that they were not." It is not certain what Fr. Lynch actually said, but the way his statement was reported in the paper implied uncertainty and the possibility that the recorded seismic events were related to the event at Wilkes-Barre. Soon the papers were mentioning in an offhand way, as though it were an established fact, that the Wilkes-Barre event of February 21 had been recorded seismographically (e.g., the *Allentown Morning Call*, February 24, 1954).

WHAT WAS IT, REALLY? Despite the denials of the coal company, what actually happened in Wilkes-Barre almost certainly was a mine collapse. This is borne out by two reports made at the time, one by Retsel and others (1954), federal mine inspectors, and the other by MacCartney and Kudlich (1954), consulting engineers. Pillar failure apparently occurred in recently abandoned workings in the Hillman vein, some 500 feet below the surface at that point. Collapse propagated upward until it reached the surface, where its effects were enhanced by the presence of more than 150 feet of Quaternary surficial deposits. The collapse seems to have been confined to the area of a broad syncline, the Lynnwood/Gas Works syncline, which contains a low-amplitude medial anticline, the Lynnwood anticline (Figures 1 and 2). More details of the collapse and its relationship to local geology are given by Scharnberger (1991).

One reason that the reports of the mine inspectors and engineers were not effective in countering the earthquake theory was that they were made public in May 1954, at which time the *Wilkes-Barre Record* was not publishing because of a strike. Thus, these reports did not get the publicity that had been accorded the earlier speculations about earthquakes.

CONCLUSION. Seismic hazard in the Eastern United States is a matter of genuine concern. Earthquake history plays an important role in the scientific investigation of this hazard; therefore, it is important to have as accurate an earthquake history as possible. A perfectly accurate record, of course, is impossible—some real earthquakes almost certainly have been lost to history, and the true cause of some ambiguous cases may never be firmly established. But we should remove "Wilkes-Barre, magnitude 5.0, February 1954" from the earthquake catalogs, because it is definitely an "earthquake that never was."

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Life in a Fossil Shellfish Community: an Excellent Outdoor Classroom and a Collector's Paradise

by John A. Harper
Pennsylvania Geological Survey

Life in the oceans has not changed much over the last 300 or 400 million years. True, many specific life forms of the Paleozoic Era, such as clams, worms, and brachiopods, have come and gone, but the roles that these now-defunct animals played are not very different from those played by modern life forms. The occupations remain the same; only the names have been changed.

This can be seen in a remarkable fossil locality in Youngwood, about 5 miles south of Greensburg in Westmoreland County (Figure 1). Some very fossiliferous Pennsylvanian rocks of the Brush Creek marine zone occur in an outcrop and associated spoil pile at the Con-

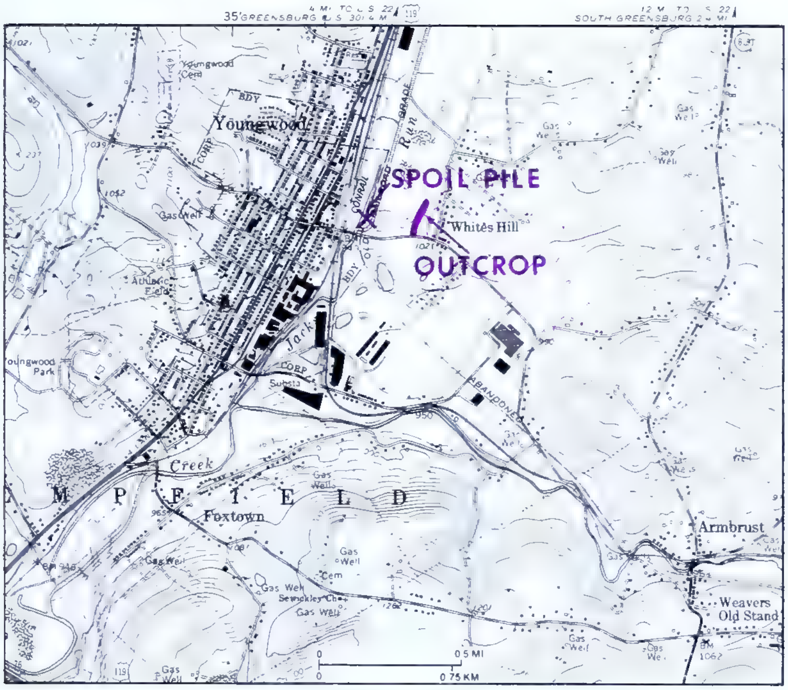

Figure 1. Location of the Youngwood fossil-collecting locality, Mt. Pleasant 7.5-minute quadrangle.

rail Industrial Park east of the town center (Figure 2). The rock was excavated from a hillside during construction of the warehouses, offices, and storage lots that occupy the park, and some of the excavated material was dumped in the vacant lot just west of the buildings. The Brush Creek is the oldest of six marine zones in the Glenshaw Formation (Conemaugh Group) in western Pennsylvania and second only to the Ames Limestone in diversity and abundance of invertebrate fossils. The Youngwood locality is particularly interesting and important because of an unusual abundance of fossils, many preserved in life position. Clams, snails, scaphopods, and other invertebrates died suddenly on the sea bottom at this locality, their shells encased in the organic-rich mudrocks for 300 million years.

The clam *Astartella*, which typically measures less than three fourths of an inch in the longest dimension, dominates the fauna. Hundreds of specimens can be collected within the space of a half hour; needless to say, the discriminating collector becomes very selective in a short time. *Astartella* can be considered the Pennsylvanian version of the cherrystone clam, making Youngwood a fabulous 300-million-year-old shell fishery (for gourmands with very small appetites—at least the clam chowder would have been plentiful). Other clams such as *Nuculopsis* and *Phestia* also occur, as well as a wide variety of snails dominated by *Pharkidonotus*, *Amphiscapha*, and *Raphistomella*. Whole and broken clam shells occur with other fossils in jumbled masses, apparently accumulated in sediment pockets during storms. Complete, uncrushed, and unbroken specimens of *Astartella* occur throughout the rock, however, standing in life position almost perpendicular to the bedding of the shale (Figures 3A and 4). These clams are similar to the Recent-age clam *Mulinia lateralis*, described by Stanley (1970) as a lagoonal species abundant in mud-bottom conditions. *Mulinia*, and by analogy *Astartella*, burrow head down at a

Figure 2. Brock University geochemist Uwe Brand examines the Brush Creek shale at the spoil pile in Youngwood.

slight angle into mud and feed through inhalent currents entering the rear of the shell near the sediment-water interface. Numerous specimens of complete snail shells can also be found in life position, their shells oriented upright in the rock (Figure 3B, 3C). Although scaphopods are relatively rare at this locality, those specimens of *Plagioglypta* that were collected were also found in life position, with the shell oriented at a low angle to the rock layers.

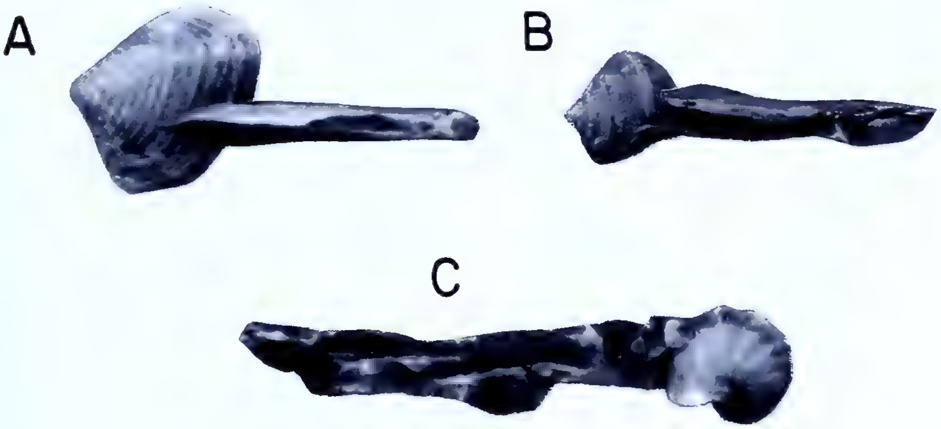

Figure 3. Fossils from the Brush Creek black shale preserved in life position. A, *Astartella*, a burrowing clam; B, *Raphistomella*, a mobile, surface-dwelling snail; C, *Pharkidonotus*, a limpet-like bellerophont snail. A fragment of rock strata has been left attached to each to indicate the life orientation of the animal.

Why are so many of the fossils at this locality found in life positions? This phenomenon is probably due to a combination of rapid death, most likely caused by oxygen depletion (hypoxia) in the water and bottom muds, and quick burial, caused by rapid sediment influx. Hypoxia and rapid sedimentation commonly occur today in such coastal areas as Texas and Louisiana. For example, Harper and others (1981) documented seasonally recurrent hypoxia events off the coast of Texas that occurred following spring runoff periods. Increased runoff from local Texas rivers carried higher than normal loads of dissolved organic material into the ocean, resulting in large diatom blooms that declined only when the nutrients became exhausted. Calm seas in the Gulf of Mexico and the normal influx of fresh water during the summer produced intense water stratification, greatly reducing oxygen diffusion from surface waters. The dead diatoms accumulating on the sea floor attracted bacteria whose activity further helped to reduce the oxygen in the bottom waters. The final step occurred when sulfate-reducing bacteria took over, generating poisonous hydrogen sulfide. These conditions prevailed off the Texas coast throughout

Table 1. ***List of Fossils Observed or Collected from the Youngwood Brush Creek Locality***

FORAMINIFER
Tolypammina sp.

CORAL
Stereostylus sp.

CONULARIID
Conularia sp. cf. *C. crustula* White

BRACHIOPODS
Lingula carbonaria Swallow
Lingula lemniscata Price
Chonetinella plebeia (Dunbar and Condra)
Neochonetes granulifer (Owens)
Pulcratia sp.
Juresania sp. cf. *J. nebrascensis* (Owen)
Linoproductus sp. cf. *L. prattenianus* (Norwood and Pratten)
Composita subtilita (Hall)
Crurithyris planoconvexa (Shumard)
Miscellaneous spines

OSTRACODES
?*Bairdia* spp.

GASTROPODS
Euphemites vittatus (McChesney)
Bellerophon (Bellerophon) stevensianus McChesney
Pharkidonotus percarinatus (Conrad)
Retispira tenuilineata (Gurley)
Knightites (Cymatospira) montfortianus (Norwood and Pratten)
Patellilabia (Patellilabia) tentoriolum Knight
Amphiscapha catilloides (Conrad)
Amphiscapha reedsi (Knight)
Amphiscapha subrugosa (Meek and Worthen)
Raphistomella (Raphistomella) grayvillense (Norwood and Pratten)

GASTROPODS *(continued)*
Worthenia tabulata (Conrad)
Phymatopleura brazoensis (Shumard)
Palaeostylus (Pseudozygopleura) scitula (Meek and Worthen)
Meekospira peracuta (Meek and Worthen)
Strobeus primogenius (Conrad)
Girtyspira minuta Knight

CEPHALOPODS
Brachycycloceras sp.
Pseudorthoceras knoxense (McChesney)
Metacoceras mcchesneyi Murphy

BIVALVES
Nuculopsis girtyi Schenck
Nuculopsis croneisi Schenck
Phestia arata (Hall)
Phestia bellistriata (Stevens)
?*Septimyalina* sp.
Aviculopecten sp.
Euchondria sp.
Palaeolima triplistriata (Stevens)
Schizodus wheeleri (Swallow)
Permophorus costatiformis (Meek and Worthen)
Astartella concentrica (Conrad)
Edmondia anodontoides (Meek)
Prothyris (Prothyris) elegans Meek

SCAPHOPOD
Plagioglypta meekiana (Geinitz)

STARFISH
Syntomospina kuehni Morris, Rollins, and Shaak
Starfish plates

CRINOIDS
Assorted crinoid columnals and calyx plates

much of the summer and only ceased when water mixing elevated oxygen levels in late summer and early autumn.

Did something like this happen periodically at Youngwood 300 million years ago? It seems entirely likely. The Brush Creek typically consists mostly of mudrocks having relatively high organic content. Geochemical analyses of other Brush Creek localities in western Pennsylvania indicate that the sediments were oxygen poor during deposition, especially in areas where original aragonitic mollusc

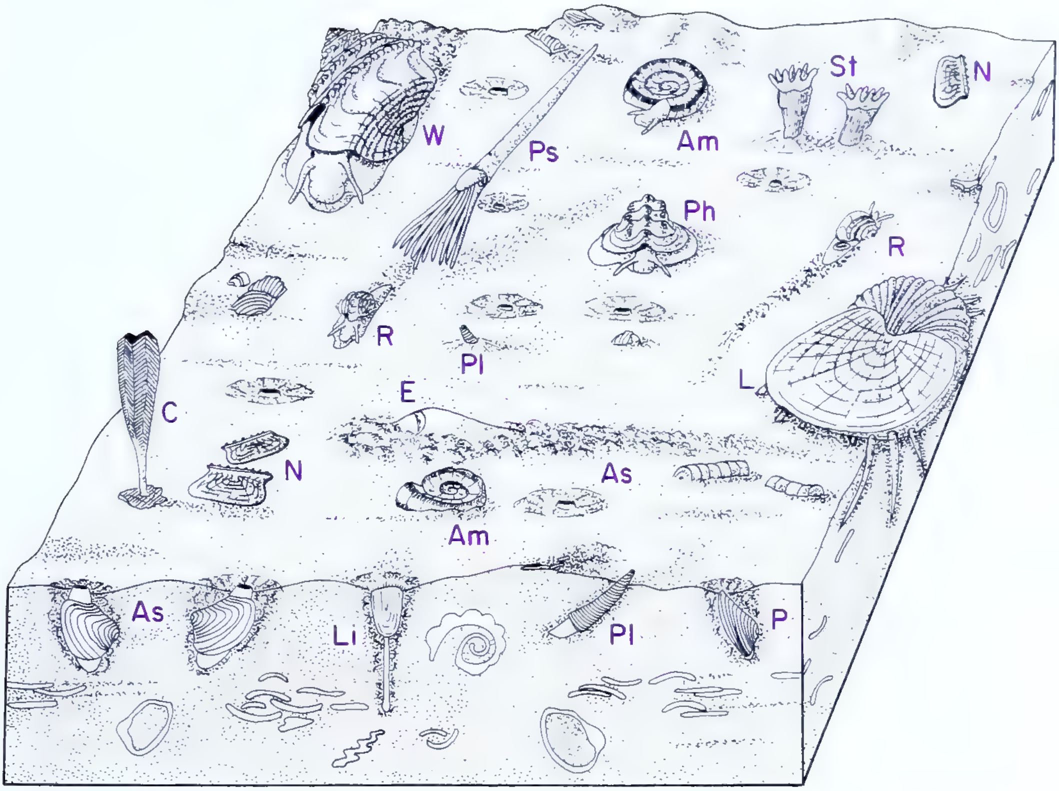

Figure 4. Reconstruction of the fossil community at the time of deposition of the Brush Creek shale at Youngwood. Abbreviations refer to bivalves *Astartella* (As) and *Phestia* (P); gastropods *Amphiscapha* (Am), *Euphemites* (E), *Pharkidonotus* (Ph), *Raphistomella* (R), and *Worthenia* (W); scaphopod *Plagioglypta* (Pl); cephalopod *Pseudorthoceras* (Ps); brachiopods *Lingula* (L), *Linoproductus* (Li), and *Neochonetes* (N); coral *Stereostylus* (St); and conularid *Conularia* (C).

shells are preserved (Cercone and others, 1989). Aragonite, a form of calcium carbonate that most molluscs use to form their shells, is unstable under normal conditions; it tends either to recrystallize to calcite or dissolve completely after burial. In unusual cases, however, such as in some Brush Creek localities where the rock has a high organic content, the aragonite may be preserved in its original form and structure. The presence of abundant aragonitic shell material in the Brush Creek shale is strong evidence for high organic content and hypoxic conditions in the muds deposited at Youngwood. Hypoxic conditions may be further corroborated by the absence of noticeable bioturbation (reworking of sediment by living organisms) in the rock. Invertebrate shells are rarely preserved in any preferred orientation because worms and other sediment-churning animals tend to disturb or disarticulate lifeless skeletons. Hypoxic bottom waters and muds have a deleterious effect on these animals, however, just as they do with the normal inhabitants. In addition, rapid deposition of muds during the hypoxic events would have quickly buried even the most mobile surface dwellers.

Teachers interested in visiting this outdoor classroom should be aware that the actual outcrop is situated in a restricted area belonging to Bell of Pennsylvania and that permission to enter the premises may not be granted. The spoil piles should present no problem for visitors, however, and are especially recommended because of their accessibility. Fossil collectors should restrict themselves to the spoil piles. From U.S. Route 119 in Youngwood, turn east on Depot Street, cross the railroad tracks and turn left almost immediately. The spoil piles are located near the bushes on the right in the unpaved lot directly ahead. The lot has plenty of parking even for large groups. It will not be difficult to find the spoil piles; the Brush Creek has a noticeable salt-and-pepper aspect because of the chalky whiteness of the aragonitic shells in the black shales.

The following notes will be of interest to fossil-collecting enthusiasts: (1) The name *Raphistomella* may look strange and new to experienced collectors of Pennsylvanian fossils. Batten (1989, p. 7, 8) pointed out that the European Triassic genus *Raphistomella* Kittl, 1891 was indistinguishable from the Paleozoic genus *Glabrocingulum* Thomas, 1940. By the rules of zoological nomenclature, the older name has precedence. (2) Numerous specimens of the tiny brittle star *Syntomospina* (less than one-half inch from arm tip to arm tip) were found on one or more bedding planes in the rock at this locality. Fossil starfish of any sort are typically very rare, so here is a treasure worth looking for. (3) Some of the better preserved molluscs retain color-band patterns. These are especially prominent in specimens of *Amphiscapha* that have buff-colored shells. Inasmuch as most of the fossils at this locality have a black coating, these specimens tend to stand out upon close examination.

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EARTH SCIENCE TEACHERS' CORNER

"Out of the Rock": A New Video on Mining and Minerals

by John H. Barnes
Pennsylvania Geological Survey

A new videotape from the U.S. Bureau of Mines, "Out of the Rock," provides 29 minutes of well-chosen visual images that nicely complement an informative and interesting narrative on the role of mining and minerals in the modern world. The following are among the points presented:

—No matter how complex or simple a finished product may be, or how routine its use, it exists because of something found in the ground that we can mix, mold, melt, cast, extrude, alloy, stamp, or stretch into something useful. But first, it has to be mined. Mining is not a gentle process.

—Some materials considered essential today will become less and less important. New ways are found to use materials once thought common and without value.

—Technological achievements come with a price—a total dependence on an ever-increasing flow of raw materials and the dangerous illusion that there are no limits to expansion.

—Mining can never end. The driving force is human consumption.

After watching this video, the viewer is left to realize that mining is something without which no semblance of civilized life could exist, and that modern life is forcing change on the mining industry in ways that might not be expected. For example, as a consumer-driven society demands more in the way of products with elaborate packaging and throw-away convenience, a tremendous strain is placed not only on waste-disposal facilities, but also on the mining industry, which must produce the raw materials necessary to make the new products and packaging.

The ramifications of our demands on the mining industry extend beyond our nation's borders. We have had to turn to less-developed nations, some with unstable governments, for minerals that are absolutely essential to manufacture products in such fields as medicine, national defense, and aviation. Meanwhile, some of these supplier nations aspire to develop their own industrial potential, thus creating even more demand for the world's limited supply of resources.

Recycling helps, but it is not a replacement for mining, as some might think. It is pointed out that even if billions of dollars worth of goods were not lost to corrosion each year and 100 percent recycling were possible, our nation's increasing demand for resources still could not be met.

The emphasis of the video is on metallic minerals, but the problem of increasing demand and decreasing supply also affects nonmetallic resources, such as sand and gravel, especially in heavily populated states such as Pennsylvania. Although this problem is not discussed, the video does demonstrate the importance of these resources in our lives.

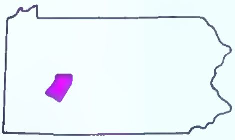
Overall, because it does a good job of letting the viewer see the world a little differently, this video is well worth viewing. To quote from the narration,

> There are few times, if any, that we stop to consider the importance of mining and minerals. We tend to focus, instead, on the more tangible end uses of raw materials, on the products and conveniences they make possible. Quality of life, national security, the stability of domestic and world economies, science, industry, and the arts all depend on the mineral resources we take out of the rock.

"Out of the Rock," written by William J. Gage and Gerald Weinbren, may be borrowed by any responsible group or individual by writing to Audiovisual Library, U.S. Bureau of Mines, Cochrans Mill Road, P.O. Box 18070, Pittsburgh, PA 15236. Please include your telephone number, specify whether you require the VHS or U-Matic format, and indicate a first and second choice for a viewing date. It can also be purchased, $14 for VHS or Beta or $21 for U-Matic, from Video Transfer, Inc., 5710 Arundel Avenue, Rockville, MD 20852.

NEW PUBLICATION

Water Resources Data for Indiana County



The U.S. Geological Survey has released a compilation of hydrologic data collected in Indiana County from May 1986 through September 1988. This report, by Donald R. Williams of the U.S. Geological Survey and Thomas A. McElroy of the Pennsylvania Geological Survey, includes inventory data for 517 wells and 133 springs, water-quality data for 300 wells and 118 springs, hydrographs for 19 wells, aquifer-test data for 22 wells, and extensive data on surface water and precipitation in the South Branch Plum Creek and Cherry Run basins. Prepared in cooperation with the Pennsylvania Geological Survey and the Indiana County Commissioners, U.S. Geological Survey Open-File Report 90–384 consists of a 147-page book and two 1:50,000-scale plates on which sample sites are plotted. **Water Resources Data for Indiana County, Pennsylvania** can be purchased for $31.25 (paper) or $5.50 (microfiche) from USGS Book and Report Sales, Box 25425, Denver, CO 80225. Please make checks payable to *Dept. of the Interior—USGS.*

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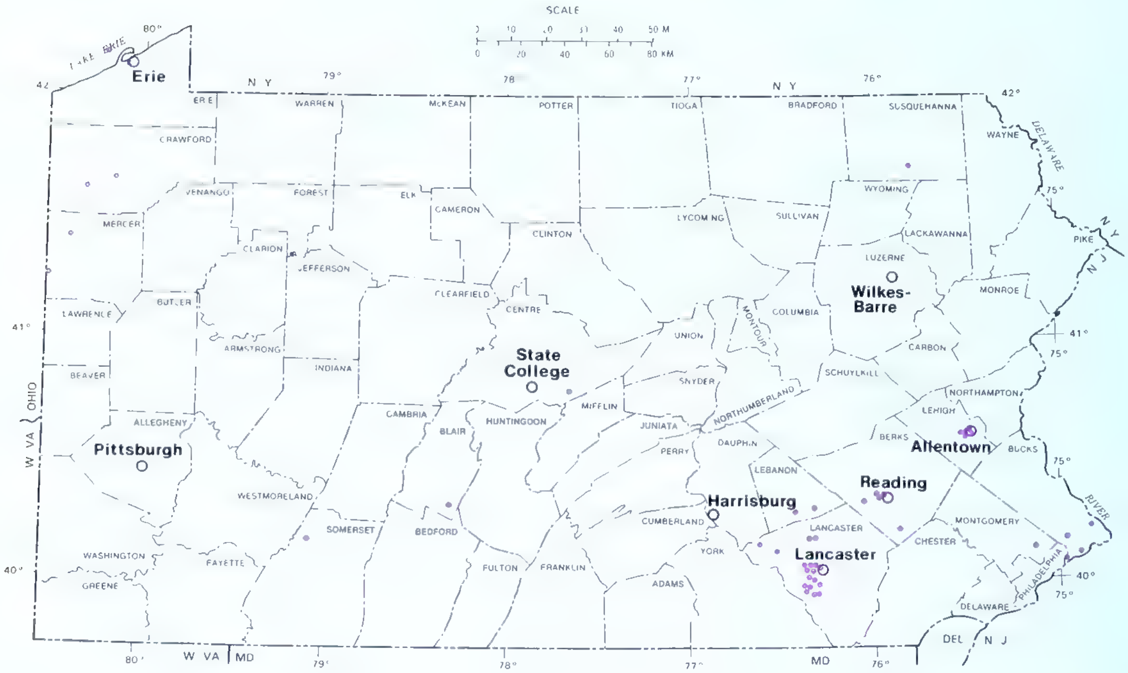
IN COOPERATION WITH THE U.S. GEOLOGICAL SURVEY

TOPOGRAPHIC MAPPING
GROUNDWATER-RESOURCE MAPPING

HISTORIC EARTHQUAKE EPICENTERS IN PENNSYLVANIA

(See article on page 3)



EXPLANATION

●

Historic earthquake epicenter

Based on known earthquake history of Pennsylvania through August 1992. Many locations are approximate.

SOURCE: Scharnberger, C. K. (1989), *Earthquake hazard in Pennsylvania*, Pennsylvania Geological Survey Educational Series 10, p. 8; and Scharnberger, C. K., oral communication, 1992.

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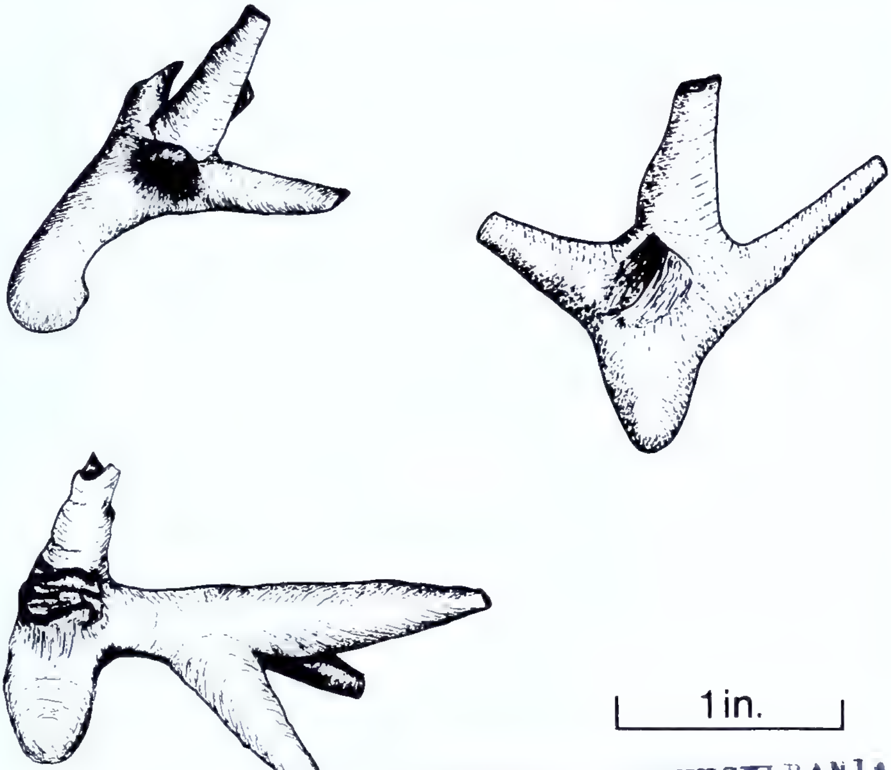

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ON THE COVER

Bulbous holdfasts of the crinoid *Ancyrocrinus* from the "garden" beds at the Swope pit, near Turbotville in Northumberland County. These rootlike structures anchored the crinoids to the substrate. For further details concerning these and other fossils at the Swope pit, see the article on page 7. Sketch by John G. Kuchinski.

PENNSYLVANIA GEOLOGY

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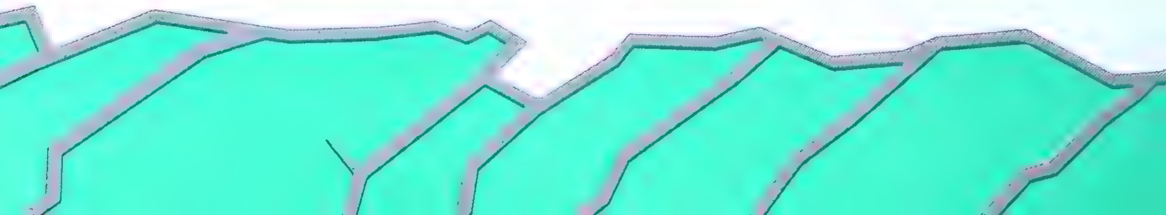

STATE GEOLOGIST'S EDITORIAL

In Our Own Back Yard

(the Status and Future of Geologic Mapping)

Nearly a decade ago, the Board on Earth Sciences of the National Research Council (NRC) began to examine the geologic mapping program of the U.S. Geological Survey and to assess the future needs of geologic mapping in our nation. Geologic mapping, originally oriented toward discovery of mineral resources, now provides the basic data used for most wise human interactions with our earth. Determining the location of groundwater resources and finding suitable sites for development and waste repositories are but a few of the many examples that can be cited in which geologic mapping is critical to making proper decisions. The results of the NRC studies, published by the National Academy of Sciences, were troubling in that they concluded that no national program existed to address the clearly evident and increasing need of users for large-scale (i.e., detailed) geologic maps from which informed land management decisions could be made. Further, it was found that only about 20 percent of the nation's surface is mapped to an accuracy and scale presently needed. This situation has come about even though geologic maps have long been recognized as "rank[ing] with mathematical equations as being amongst the most effective ways ever devised of conveying vast amounts of special information in a minimum amount of space" (John C. Reed, Jr., *Geotimes*, June 1989, p. 6) . Geologic maps, however, require long periods of physical exertion, extensive data measurements, and synthesis. Publishing the results of these efforts is necessarily slow and generally results in fewer numbers of reports than other styles of geologic research, thereby reducing its attractiveness to geologists seeking rapid academic or professional recognition.

The USGS responded to the Academy's published reports by establishing a federal program for geologic data acquisition and a cooperative program (COGEOMAP) with state geological surveys. It was recognized that any national geologic mapping program must include the efforts of state geological surveys, which have historically prepared geologic maps as one of their principal activities. Unfortunately, federal funding for these efforts never fully addressed national needs; geologic mapping remains at inadequate levels in our nation.

Spearheaded by the member Surveys of the Association of American State Geologists and in cooperation with numerous national, geological, environmental, and mineral-resource organizations

(continued on page 6)

TELL-TALE TALCS – Chemical Clues to Unravel the Earth's Secrets

by Robert C. Smith, II
Pennsylvania Geological Survey

While searching for mineral resources along the Susquehanna River, Lancaster County, during January 1989, the tell-tale orange color of soil derived from ultramafic and mafic rocks was observed. This color was detected at the contact of the Cardiff Conglomerate and the Peters Creek Formation on the southeastern side of an enigmatic bedrock configuration known as the Peach Bottom structure in the Piedmont physiographic province (Figure 1). Within several minutes, a 2-m- (7-ft-) thick zone of noneconomic talc-magnesite schist was uncovered with a shovel (this tool being at least as useful as a hammer in the Piedmont) and was channel sampled. Knowing of Charles Behre's (1933) hypothesis that the Peach Bottom structure is a syncline, a folded bedrock structure in which rocks seen on one side might also be found on the opposite side, an attempt was immediately made to confirm the presence of a similar section on the northwest side of the structure. There, a few tens of meters above the level of the railroad tracks, a small, more subtle area of orange-colored soil containing a few small talc chips was detected. Using a bit more effort because of the defending tree roots, the tell-tale area on the northwestern side was exposed and also channel sampled. Mineralogic and lithologic similarity between these rocks and those originally exposed on the southeastern side provided circumstantial evidence that they are genetically related. As the analyses of the two samples ("Peach Bottom Southeast" and "Peach Bottom Northwest") reveal (Table 1), there is a tale to be told. Although this certainly is not the last of the tales to be told here, it is desirable to share this data with others so they can decide if a "tall tale" is being told.

Talc can form by the alteration of at least three different rock types: ultramafic rocks, mafic rocks, and dolomitic rocks. Samples from the two Peach Bottom talc occurrences were compared chemically with talc samples from three other occurrences in the area, because geochemistry can help one to determine the kind of rock from which each was derived. Surprisingly, the very high chromium and nickel contents (Table 1) of the five samples suggest that *all* were derived from ultramafic rocks! This is not a surprise for the "Scout

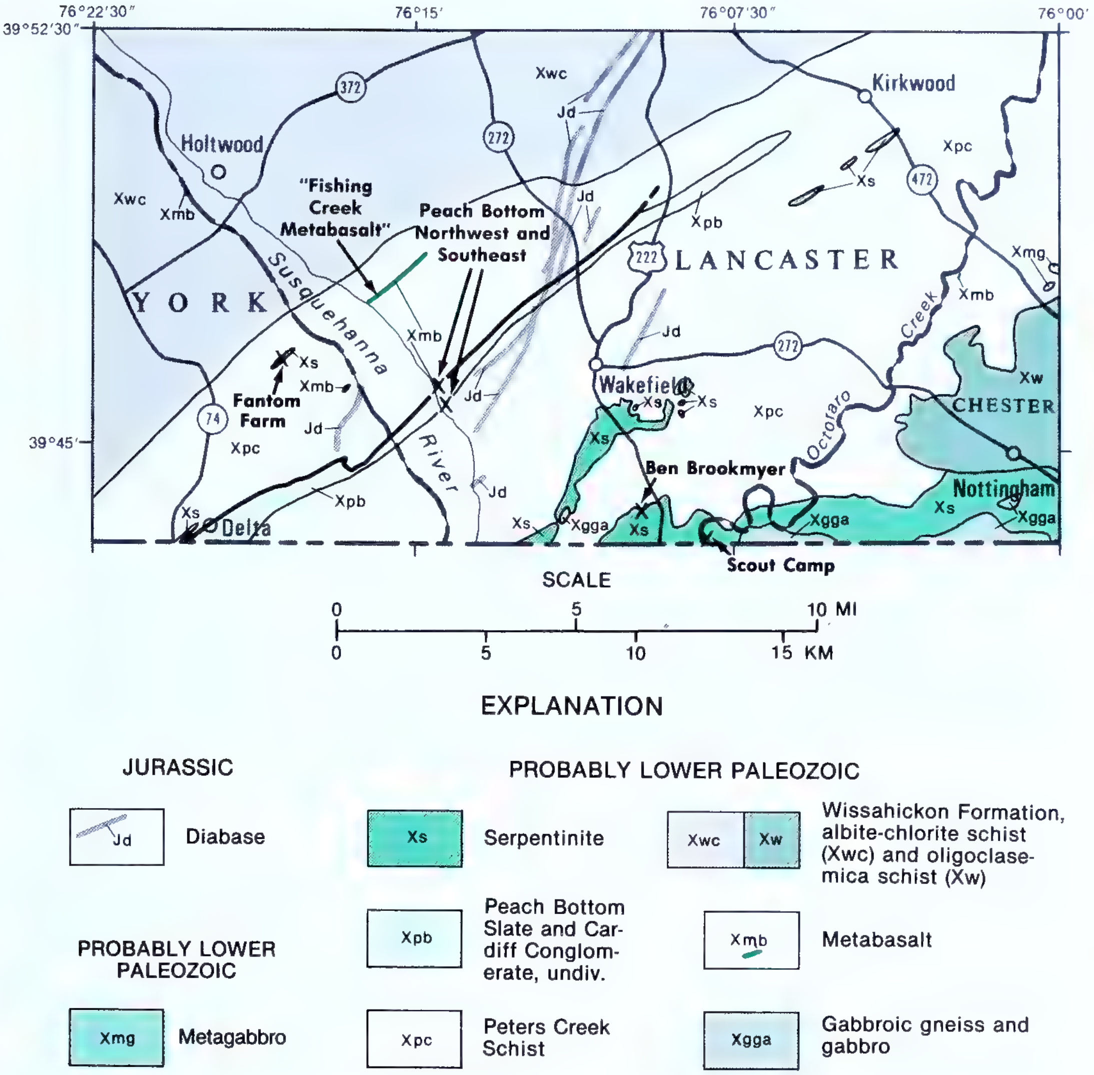

Figure 1. Geologic map of part of southeastern Pennsylvania (modified from Berg and others, 1980) showing the locations of sampled talcs.

Camp" sample (Figure 1), which is from a shear zone near the serpentinite-pyroxenite contact within the Baltimore Mafic Complex. Nor was it a surprise for the "Ben Brookmyer" sample, which is from a potentially commercial talc prospect in serpentinite in what a talc miner would term a "blackwall" setting, near the north margin of the Baltimore Mafic Complex. The surprise was the "Fantom Farm" occurrence, which is on apparent regional strike with a recently rediscovered metabasalt horizon, and which might, therefore, be expected to have been derived from mafic rocks. We shall return to the case of the "Fantom Farm" shortly.

Table 1. ***Composition of Some Talc Channel and Composite Chip Samples***

(All values are in parts per million; 10,000 parts per million equals 1 percent)

	Peach Bottom Northwest, Lancaster County	*Peach Bottom Southeast, Lancaster County*	*Fantom Farm, York County*	*Scout Camp, Chester County*	*Ben Brookmyer, Lancaster County*
Ba	10	10	<10	<10	<10
Co	100	100	70	70	50
Cr	1,500	2,000	2,000	2,000	1,500
Fe	50,000	30,000	15,000	15,000	15,000
Mn	700	1,000	150	500	300
Mo	2	2	<2	<2	<2
Ni	1,500	1,000	1,500	1,500	1,500
Sc	20	20	<10	<10	<10
Ti	3,000	2,000	50	<20	30
V	70	100	20	10	10
Y	20	50	<10	<10	<10
Zr	50	20	<20	<20	<20

From the similarity of the composition of the Peach Bottom Northwest and Peach Bottom Southeast samples, it seems likely that they were either from the same or an extremely similar body, even though they were collected from opposite sides of the Peach Bottom structure. This suggests that Behre was, at least in part, correct. Based on the somewhat elevated contents of the elements Ba, Mo, Sc, Ti, V, Y, and Zr, it is inferred that the ultramafic parent of the talc could have somehow interacted with or possibly assimilated a small amount of basalt or some other continental or island-arc material. These observations, together with the fact that ultramafic rocks, especially talc, tend to become the foci of faults, suggest that the basal Peach Bottom talc (and perhaps related serpentinite bodies, such as the larger one near Delta) constitute the slippery surface or zone of weakness upon which the Cardiff Conglomerate, Peach Bottom schist (an informal unit of Behre, 1933), and Peach Bottom Slate (in ascending order) might have been thrust into the area, presumably during the Taconic orogeny approximately 450 million years ago. According to this hypothesis, the Peach Bottom thrust would have been folded into a syncline somewhat later. This synclinal aspect is not very surprising in view of the circumstantial evidence that the Arvonia and Quantico synclines of Virginia contain rocks that have a lithologic sequence similar to those at Peach Bottom. Thus, the rocks within the Peach Bottom structure in this area are probably younger than those both immediately to the northwest and southeast. By analogy to rocks in the Arvonia and Quantico structures, the clastic rocks within the Peach Bottom structure might also be of Ordovician age.

Meanwhile, back at the "Fantom Farm" talc occurrence, apparently conflicting evidence presented itself in the form of an ultramafic pod, which was later transformed into talc, along the regional strike of a recently rediscovered mafic body, herein informally called the "Fishing Creek metabasalt" (Figure 1). The affinity of this metabasalt, which was overlooked for many years because the ink color used to depict it on Knopf and Jonas's (1929) map closely resembled that used for more common diabase, is as yet uncertain, but the alignment of metabasalt with the northwesternmost known ultramafic pod suggests that one might be dealing with the edge of an ophiolitic mélange (A. A. Drake, Jr., personal communication, 1989) or, in other words, a mixture of various types of ocean-floor and related "sweepings." Such an edge might mark the boundary between two terranes that originated somewhat independently of each other and were later thrust together.

A complicating feature in the exposure through the Peach Bottom structure along the east shore of the Susquehanna River is an apparent 3.6-m- (11.8-ft-) wide mylonitic fault zone at Behre's (1933) contact between Peach Bottom Slate on the northwest and Peach Bottom schist on the southeast. The material in this apparent fault zone consists of ultrafine-grained, sheared insoluble residue that is now composed of dark mica and "carbon," and rounded, milky quartz balls that are extremely deformed internally. It is suggested that the quartz might have come from veins of Taconic age that were later structurally ball-milled into their present, deformed, floating condition by high-angle, post-Taconic faulting. Based on this and the circumstantial evidence of a few small cross folds observed in an ocean-floor metabasalt just north of the Peach Bottom structure, it was hypothesized that this fault might be a right-lateral Alleghanian or even Acadian fault. In the presence of such evidence-concealing structures that are only vaguely understood by the present author, the trail to any ore deposits, the original purpose for looking at these outcrops, is expected to be very faint.

Geochemistry is but one of the tools available to the geological sleuth. When used cautiously in combination with other observations, geochemistry can not only help to find economic ore deposits within the earth's crust (Rose and others, 1979), but, as we have seen here, also help unravel the depositional, tectonic, mineralogic, and lithologic setting of many kinds of rocks (Turekian and Wedepohl, 1961). Using similar techniques, other metabasalts in southeastern Pennsylvania are being studied in the hope of grouping them according to their affinities and economic potential. Because most of the easily discovered metallic and nonmetallic ore deposits have already been found, one should consider as many types of geological clues as are available in searching for additional deposits. Until such investigations are carried out, many big mysteries will remain unsolved.

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In Our Own Back Yard *(continued from page 1)*

and the U.S. Geological Survey, efforts were made to establish a federally authorized *and* funded national geologic mapping program. On May 18, 1992, President Bush signed Public Law 102–285, the National Geologic Mapping Act, which authorizes and sets funding limits for national activities related to geologic mapping. With this law, our country can now begin to address national needs for detailed geologic data that will become increasingly critical as our population grows and demands greater use of the available land surface and subsurface resources, both water and mineral.

Should funding be provided, successful implementation of this act will require cooperation from the entire national geologic community. Students need to be taught the value and process of geologic mapping; surveys (federal and state) need to support geologic mapping and to devise methods of rapid transfer of data and syntheses to users; users need to support efforts to provide the resources that will be required to address this national need. As with many present national problems, the solution will require long-term labors in "our own back yards." Our nation and the geologic community need to make a commitment to long-term geologic mapping goals if the citizens of future generations are to possess the basic data that will allow use of our earth in a responsible manner.

Donald M. Hoskins

Donald M. Hoskins
State Geologist

Sea Lilies, Corals, and Lamp Shells in a Fossilized Devonian "Garden," Northumberland County, Pennsylvania

by William E. Kochanov and Jon D. Inners
Pennsylvania Geological Survey

Throughout central Pennsylvania, the Middle Devonian Mahantango Formation has long been known for the abundance and diversity of its invertebrate fossils. In fact, nearly 40 percent of the fossil sites listed for central and eastern Pennsylvania in *Fossil Collecting in Pennsylvania* (Hoskins and others, 1983) are in this formation. Even in the Mahantango, however, exposures of fossiliferous bedrock are often elusive. New roadcuts and borrow pits may yield only a few poorly preserved fossils in a mountain of rock. Once in a while, however, the collector gets lucky and finds an exposure where the fossils are many and the preservation is excellent. And once in a great while, a site is discovered that yields highly unusual or rarely preserved fossils. Such was the experience of the senior author while searching for trilobites in the Turbotville area of Northumberland County. Almost inadvertently, he stumbled upon an abandoned Mahantango shale pit containing an abundance of well-preserved invertebrate fossils in association with excellent specimens of the stony "roots" of sea lilies, or crinoids. In short, he had found the fossilized remains of a 385-million-year-old Devonian "garden"!

LOCATION. The Mahantango "garden spot" is located in Lewis Township about 2 miles north of Turbotville (Figure 1; 41°7′47″N/76°45′43″W, Muncy quadrangle). To reach the site, take the Turbotville exit off Interstate Route 180 and travel on Pa. Route 54 east towards Turbotville. Drive approximately 1 mile, turn north on SR (State Route) 1011 (Warrior Run Road), proceed about 1.4 miles, and turn east on SR 1010. The borrow pit lies on the north side of the road, approximately 0.2 mile from this last intersection. There is room to park one or two vehicles on the floor of the pit.

Collecting at the site is fairly easy, but be wary of a drop of about 5 feet along one side of the outcrop, and take proper safety precautions to avoid a fall. Mr. Swope of Turbotville owns the site, and he has generously given permission for individuals or groups to collect fossils there. As with all collecting sites, whether on public or private

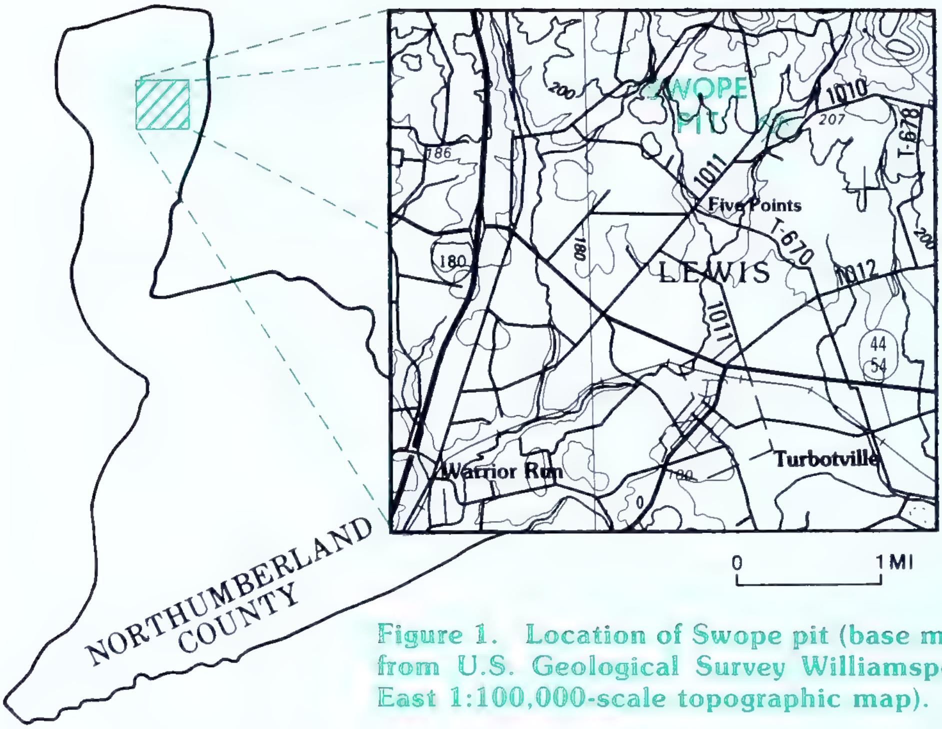

Figure 1. Location of Swope pit (base map from U.S. Geological Survey Williamsport East 1:100,000-scale topographic map).

property, please respect the rights of others. Do not litter; if you see litter, pick it up and dispose of it properly. Also, do not "over collect"—leave some fossils for others to enjoy.

STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENT. The outcrop exposes part of the lower member of the Mahantango Formation (Faill, 1979). As shown on the generalized stratigraphic column (Figure 2), the rocks at the Swope borrow pit grade upward from a medium-dark-gray fissile shale to a calcareous clay shale and argillaceous limestone. The main fossil-bearing zone—the "fossil garden"—is located at the level of the first bench (Figure 3). This layer corresponds to the argillaceous limestone and calcareous clay shale highlighted in Figure 2. Fossils are also found above this bench, but they appear to be less common and confined to thin layers.

The change in lithology from fissile shale to argillaceous limestone probably reflects a transgressive or onlap period during the Middle Devonian when shorelines encroached on land and seawater deepened. The presence of crawling (trilobites), grazing (gastropods), burrowing (bivalves, worms), and filter-feeding organisms (crinoids, bryozoans, and brachiopods, or lamp shells) indicates that "optimal" environmental conditions created a variety of ecologic niches.

The variations in lithology throughout the section suggest that there was alternating deposition of terrigenous and marine (carbon-

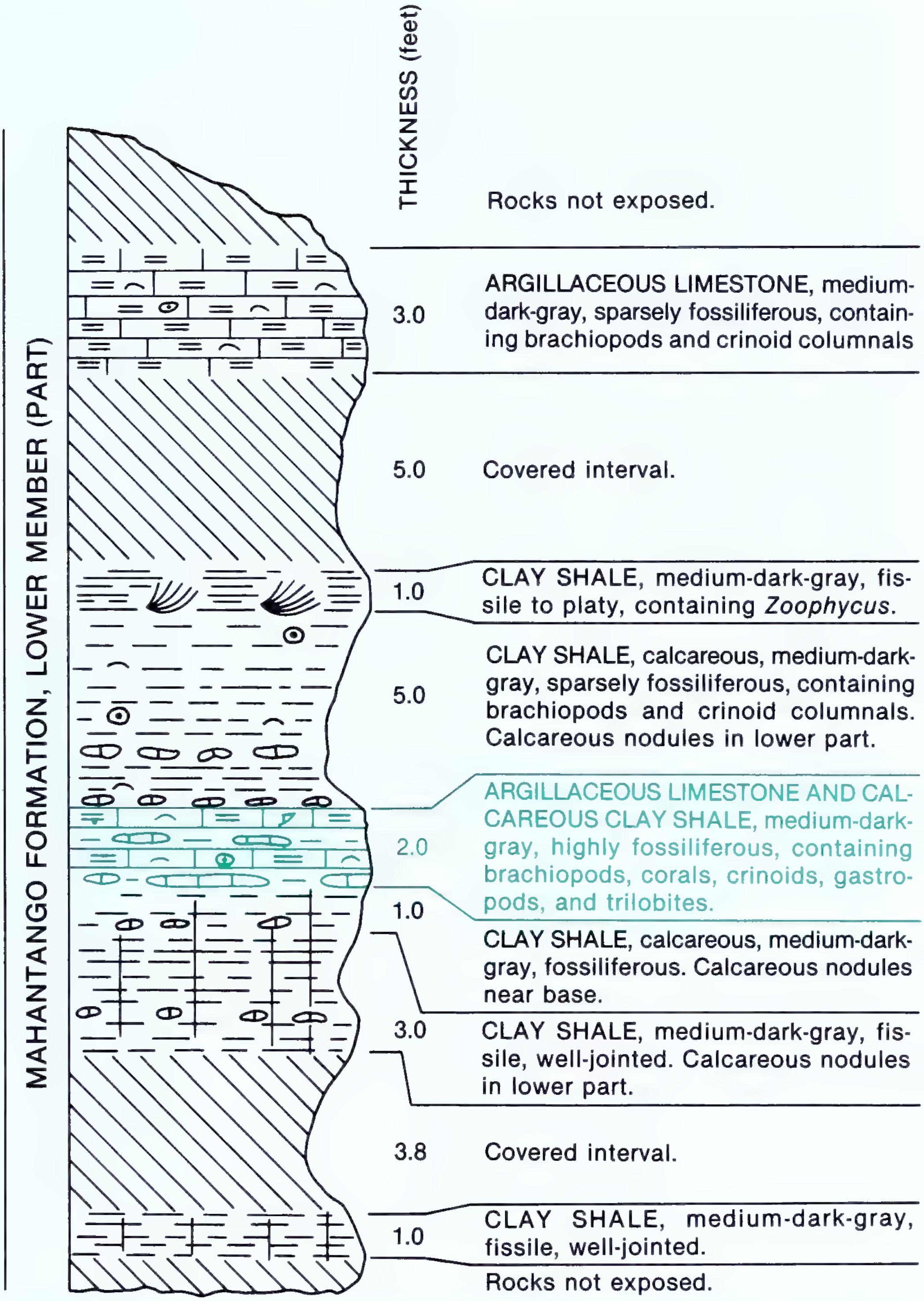
MAHANTANGO FORMATION, LOWER MEMBER (PART)
THICKNESS (feet)
Rocks not exposed.
3.0
ARGILLACEOUS LIMESTONE, medium-dark-gray, sparsely fossiliferous, containing brachiopods and crinoid columnals
5.0
Covered interval.
1.0
CLAY SHALE, medium-dark-gray, fissile to platy, containing *Zoophycus*.
5.0
CLAY SHALE, calcareous, medium-dark-gray, sparsely fossiliferous, containing brachiopods and crinoid columnals. Calcareous nodules in lower part.
2.0
ARGILLACEOUS LIMESTONE AND CALCAREOUS CLAY SHALE, medium-dark-gray, highly fossiliferous, containing brachiopods, corals, crinoids, gastropods, and trilobites.
1.0
CLAY SHALE, calcareous, medium-dark-gray, fossiliferous. Calcareous nodules near base.
3.0
CLAY SHALE, medium-dark-gray, fissile, well-jointed. Calcareous nodules in lower part.
3.8
Covered interval.
1.0
CLAY SHALE, medium-dark-gray, fissile, well-jointed.
Rocks not exposed.

Figure 2. Stratigraphic section (part of the lower member of the Mahantango Formation) exposed in the Swope pit. Note the position of the "fossil garden" beds, shown in color.

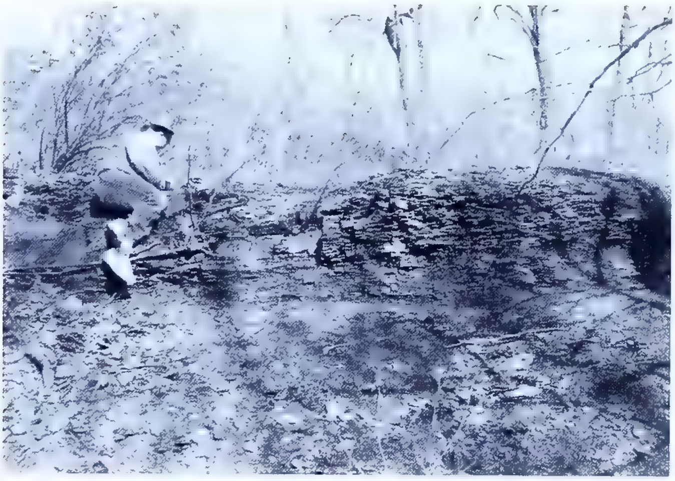

Figure 3. Highly fossiliferous crinoid-coral-brachiopod beds (the "fossil garden") forming a resistant bench in the lower part of the Swope pit.

ate) muds, the marine mud becoming more common as time went on. The fine-grained sediment and the random orientation of the fossils indicate relatively quiet water. Strong currents would have given a preferred orientation to the shells of the organisms as well as remove or winnow mud from the sediment being deposited. The lack of distinct bedding partings throughout much of the exposed section is mainly due to disturbance of the substrate by burrowing organisms. (Note particularly the *Zoophycus*-swirled clay shale about 5 feet above the highly fossiliferous bed.) Only the 6 or 7 feet of fissile, thinly laminated shale exposed at the base of the section appears to be undisturbed by burrowers.

FOSSILS. Table 1 is a list of the fossils that have been identified from the Swope pit, most of which are from the beds composing the "fossil garden." Although most of the fossils occur as internal and external molds (from which the original carbonate shells have been dissolved), some of the the crinoidal fragments and corals and a few of the trilobites and brachiopods retain their calcite "skeletons." Many of the corals (both rugose and tabulate forms) can be "popped out" of the rock without falling apart. Both the outer calcite shell and the internal molds of individual brachiopods can be collected easily. Whole specimens as well as heads and pygidia ("tails") of the trilobite *Phacops rana* (Pennsylvania's official state fossil) are most common in the top foot of the first bench.

If you are careful when splitting the fossiliferous rocks, you may expose structures that appear as short, thick, tapering roots or branches (see cover). They are "roots" in the sense that they are used as anchors, or holdfasts, of crinoids. Crinoids, the sea lilies, are echinoderms and are related to starfish and sea urchins. The thick and bulbous nature of the holdfast is due to a secondary growth of

Table 1. ***Invertebrate Fossils from the Swope Borrow Pit***

(Abbreviations are as follows: va, very abundant; a, abundant; c, common; unc, uncommon; r, rare. See Ellison, 1965, and Hoskins and others, 1983, for illustrations of representative specimens.)

CORALS
Tabulate
- *Trachypora* sp., va
- *Favosites* sp., r
- *Pleurodictyum styloporum* (Eaton), r
- *Aulopora* sp., c

Rugose
- *Heterophrentis* sp., a

BRYOZOANS
Fenestella emaciata (Hall), c
Ramose type, r

BRACHIOPODS
Rhipidomella vanuxemi (Hall), c
Douvillina inaequistriata (Conrad), c
Devonochonetes scitulus (Hall), unc
Desquamatia reticularis (Linne), r
Mucrospirifer mucronatus (Conrad), unc
Mediospirifer audaculus (Conrad), c
Delthyris sculptilis Hall, unc
Ambocoelia umbonata (Conrad), c
Athyris spiriferoides (Eaton), c

GASTROPODS
Bellerophontid, r
Bembexia sulcomarginata (Conrad), c

BIVALVES
Palaeoneilo constricta (Conrad), r
Modiomorpha sp., r
Cypricardella tenuistriata (Hall), r

CEPHALOPODS
Michelinoceras sp., r
Spyroceras sp., unc

TRILOBITES
Phacops rana (Green), c

CRINOIDS
Ancyrocrinus bulbosus Hall (holdfasts), c
Stems and isolated columnals, a

TRACE FOSSIL
Zoophycus sp.,* a

*Probably the feeding trace of a wormlike organism.

calcareous material around the primary root structure. These encrusting growths generally deform the primary root and give the resultant root its strange shape (Ubaghs, 1978). After careful searching, you may find the primary root structure, which appears as a series of interconnected, small crinoid columnals. (Do not confuse the root systems with the coral *Aulopora*!)

If you should find a holdfast, it probably will break in distinct sections. (This is also true of the primary root structures.) Such breakage is due to the fact that the holdfasts are composed of the mineral calcite, which has regular planes of weakness (cleavage) within its crystal structure.

The holdfast can be reconstructed, however. Collect all of the pieces and keep them together (empty 35-mm-film containers are excellent for this purpose). When you have returned home, set out all of the pieces on a table or other flat, stable surface. Determine how the pieces fit together, and then reconstruct the holdfast using glue.

Not all of the pieces may be there, but you should be able to put enough of the holdfast together to make an unusual addition to your fossil collection.

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EARTH SCIENCE TEACHERS' CORNER

The Geology of Radon: A Review

by John H. Barnes
Pennsylvania Geological Survey

The U.S. Geological Survey has published a 28-page booklet entitled **The Geology of Radon,** by James Otton. This booklet should be of particular interest to earth science teachers seeking materials to use in teaching about natural hazards, but also to residents of Pennsylvania in general because of the concern that has been raised in recent years about the potential danger of this odorless, invisible radioactive gas seeping into their homes from the ground. Although not a "how-to" booklet for people who are concerned about ridding their homes of radon, this colorfully illustrated booklet contains an interesting and lively discussion of the nature of radon, the ways in which it can enter a home, the methods that scientists use to measure it and predict its occurrence, and where one can turn for help.

The strongest points of this booklet are the discussions on the nature of radon and the ways in which it can invade a dwelling.

The author points out that, although radon is a product of the radioactive decay of uranium, its occurrence in buildings is dependent on other factors in addition to the abundance of uranium in the ground. Among these are the amount of pore space in the soil under the building, the presence of water in the pore space, and the extent to which the pore spaces are interconnected. He provides a good explanation of the methods by which radon enters a building, both by being drawn directly through the foundation and by entry through well water.

The booklet is not without a few flaws. A radioactivity map of the United States could be misleading because of the use of very generalized red lines, which could be misconstrued as boundaries of geologic provinces, to encircle areas of special interest. The Reading Prong, for example, is actually a well-defined narrow strip of granitic rock that extends from the east side of Reading toward Easton and into New Jersey. On this map, however, an area extending from Matamoras to Johnstown is incorrectly circled and labeled as "Reading Prong."

Although the section of this booklet on the use of geological studies to predict potential indoor radon problems is interesting, *we urge our readers to keep in mind that high levels of indoor radon have been reported in all parts of Pennsylvania and that the Department of Environmental Resources recommends that all residents of the state have their homes tested for the presence of radon.* Such tests are easy to perform using inexpensive charcoal-cannister or alpha-track detectors available at many stores and by mail order.

The importance of testing your home, rather than relying solely on maps that show the predicted potential for indoor radon problems in a region, is illustrated by a map in the booklet showing radon potential in three suburban counties in the Washington, D. C., area. A large area of Montgomery County, Maryland, is shown as having a moderate potential, and an adjacent large area of Fairfax County, Virginia, is shown as having a high potential. Such a difference in results that coincides with a county or state line can usually be explained by the use of different methods of study rather than by a real difference in nature. The author points out that, in fact, different methods of study were used to determine the radon potential in each of those counties. Such uncertainty in the prediction of radon potential plus the effects of differences in individual home construction that no map can account for make individual home testing the only sure way to determine whether you have a radon problem.

The Geology of Radon, by James Otton, published in 1992 as one in a series of general interest publications by the U.S. Geological Survey, is available free of charge by writing to Book and Open-File Report Sales, U.S. Geological Survey, Federal Center, Box 25425, Denver, CO 80225.

NEW PUBLICATIONS

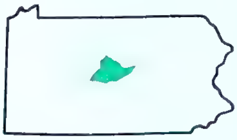
Oil and Gas Developments in Pennsylvania in 1990

The Pennsylvania Geological Survey has released Progress Report 204, **Oil and Gas Developments in 1990 with Ten-Year Review and Forecast**. The report, authored by Survey staff members John A. Harper and Cheryl L. Cozart, is the latest addition to an annual series on oil and gas developments in the state.

Topics covered for 1990 include oil and gas production and reserves, drilling and completions, exploratory and development activities, deep and shallow drilling and production, activities on state forest and park lands, and a summary of projects in progress in the Subsurface Geology Section of the Survey. In addition, the report contains a review of oil and gas developments in Pennsylvania in the past decade and a discussion of prospective trends for the 1990's, including potential new reservoirs.

Progress Report 204 may be purchased from the State Book Store, 1825 Stanley Drive, Harrisburg, PA 17103, for $2.15 plus 13¢ state sales tax for Pennsylvania residents. Orders must be prepaid; please make checks payable to *Commonwealth of Pennsylvania*.

Sinkholes and Karst-Related Features of Centre County



Sinkholes and Karst-Related Features of Centre County, Pennsylvania is the ninth in a series of open-file county-based reports issued by the Pennsylvania Geological Survey that relate to sinkhole occurrences in Pennsylvania. Released as Open-File Report 92–01 and compiled by staff geologist William E. Kochanov, the report consists of a brief explanatory text and fifteen 7.5-minute-quadrangle maps at 1:24,000 scale. The text contains a description of methods used in compiling the report, references, and a glossary. The maps show depressions (closed, semiclosed, and linear), sinkholes, surface mines, cave entrances, and bedrock geology.

Open-File Report 92–01 may be examined at the Pennsylvania Geological Survey, 2nd floor, Evangelical Press Building, Third and Reily Streets, Harrisburg. Copies of the report may be purchased by mail from the Pennsylvania Geological Survey, P.O. Box 8453, Harrisburg, PA 17105–8453, for the prepaid copying and shipping cost of $39.75, plus $2.39 state sales tax for Pennsylvania residents. Please make checks payable to *Commonwealth of Pennsylvania*.

ANNOUNCEMENTS

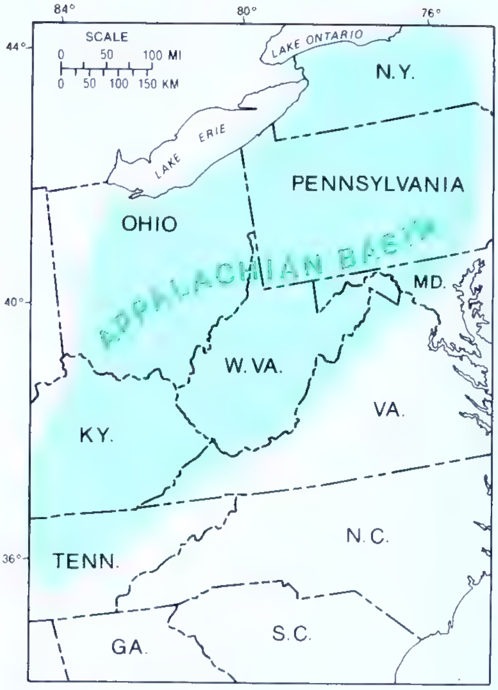
Appalachian Gas Atlas Project

The Pennsylvania Geological Survey has received a subcontract from West Virginia University (WVU) to study the geological and engineering aspects of Pennsylvania's major gas plays and to provide the federal government with a data base of the information accumulated during the project. This project is the second federally funded study awarded to the Appalachian Oil and Natural Gas Research Consortium, a group that includes the Department of Geology and Geography and Department of Petroleum Engineering at WVU, and the state geological surveys of Kentucky, Ohio, Pennsylvania, and West Virginia.

The purpose of the gas project is to identify, define, and detail the major gas plays in the seven gas-producing states of the Appalachian basin with two ultimate objectives in mind. The first objective is to help develop a national data base of information on natural gas. The data base should help the federal government determine more accurately the state of the nation's natural gas resources. The second objective is to complete and publish an atlas of the plays that will aid the natural gas industry in the basin in understanding the geological and engineering characteristics of the more important gas reservoirs. This in turn should help stimulate exploration strategies, improve production techniques, and identify conservation methods in order to promote the wise use of this natural resource.

Project participants will compile information from government, reference, and private-industry sources, filling in major gaps by conducting original research. Much of the information required for this project is in private collections. Thus, the cooperation of the oil and gas industry will be necessary in the collecting of reservoir and production information. The collected information will then be compiled into a large atlas that will include text, maps and cross sections, and tables.

Two new geologists, Kathy J. Flaherty and Joseph R. Tedeski, joined the staff of the Pennsylvania Geological Survey in 1992 to work on this project. Kathy, a native of Long Island, New York, has a degree in geology from the State University of New York at Binghamton. She comes to the project with over 10 years of experience in Appalachian petroleum geology, including working as a staff geologist with both Consolidated Gas Supply Corporation and Patrick Petroleum. She also worked as a consultant to industry for several years before joining the Survey. Joe, a Ford City, Pennsylvania, native, is a recent graduate of Indiana University of Pennsylvania. While working on his B.S. in geology, Joe was employed by the Tanoma Mining Company in Indiana County. He acquired broad experience in various geological studies of the Tanoma mine, including investigations of geological structures, examination of strata and roof conditions associated with the coal seam, and monitoring water conditions.



For those interested in additional details of the project, contact John Harper, Pennsylvania Geological Survey, Subsurface Geology Section, 500 Waterfront Drive, Pittsburgh, PA 15222-4745, telephone 412-442-4235.

Pennsylvania Survey Relocates

The Pennsylvania Geological Survey moved on June 11 to the Evangelical Press Building on Third and Reily Streets, Harrisburg. The new mailing address is

Department of Environmental Resources
Bureau of Topographic and Geologic Survey
P. O. Box 8453
Harrisburg, PA 17105-8453

The new street address is

Evangelical Press Building, 2nd floor
Third and Reily Streets
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Telephone numbers remain the same. There will be more information concerning the move in the upcoming summer issue of *Pennsylvania Geology*.

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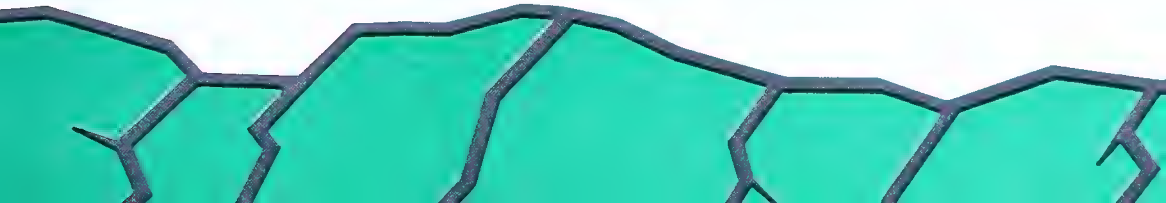

STATUS OF MODERN GEOLOGIC MAPPING IN PENNSYLVANIA

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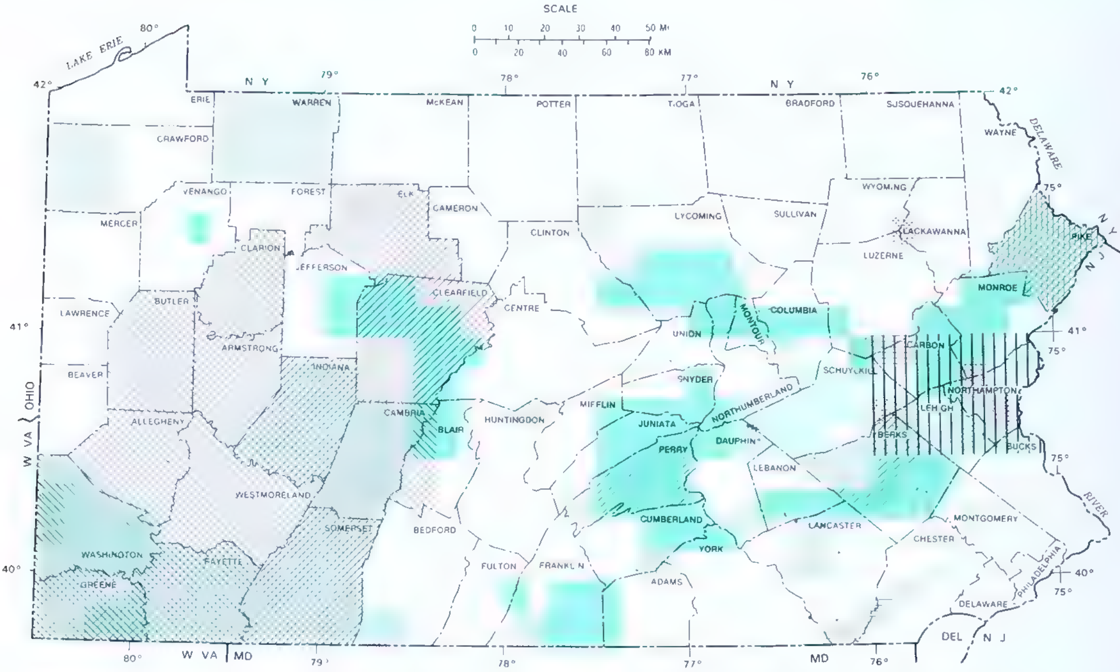

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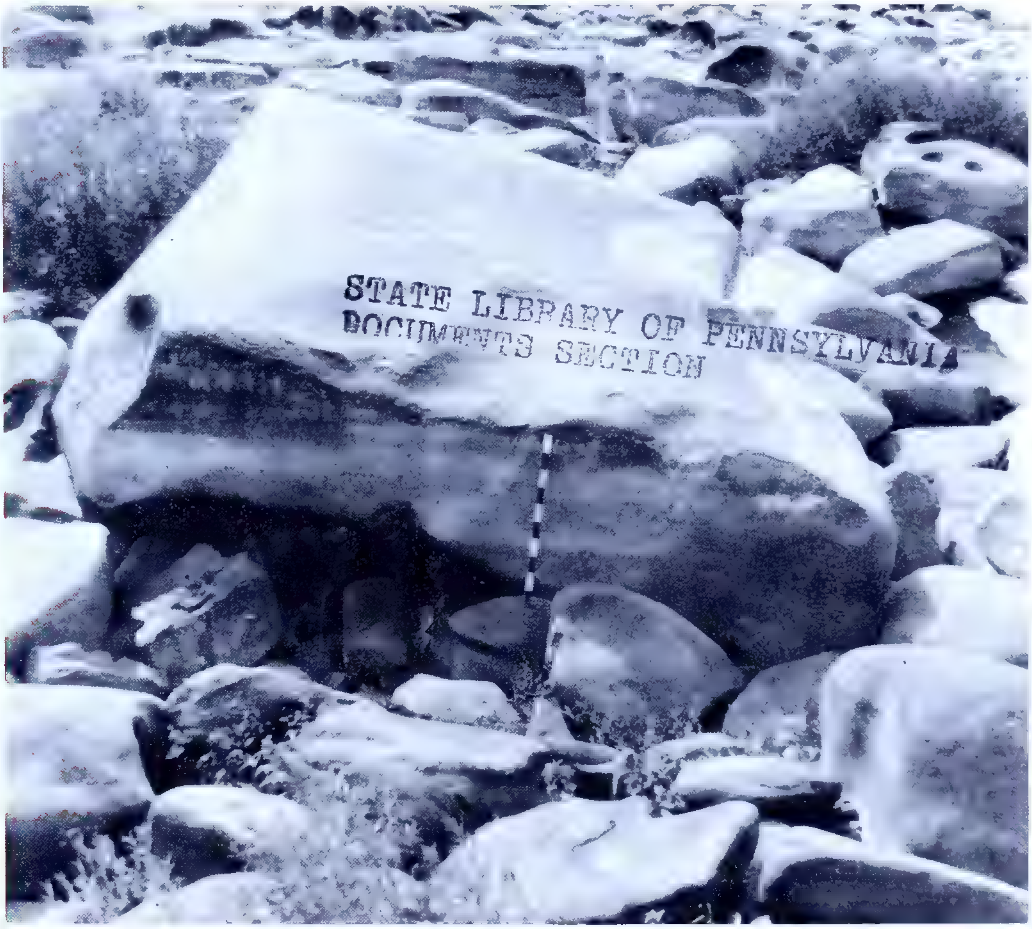

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ON THE COVER

An accumulation of diabase blocks on the bed of the Susquehanna River at Conewago Falls, northwestern Lancaster County. The blocks were presumably moved by catastrophic flow created by an outburst of glacial Lake Lesley during pre-Illinoian glaciation (see article on page 2). Upstream is to the right. The large block is 30 by 15 by 3 feet; intervals on the scale are 10 cm. Photograph by W. D. Sevon.

PENNSYLVANIA GEOLOGY

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VOL. 24, NO. 2 **SUMMER 1993**

STATE GEOLOGIST'S EDITORIAL

The Rocks of Summer

Pennsylvania's summers generally produce a natural cycle of lessened rainfall and lowered streamflow during which rocks, normally obscured by winter's ice and spring's high water, become more apparent along our stream courses. The "ribs" of Pennsylvania, the many rock layers tilted to expose their edges by internal earth stresses over 200 million years ago, begin to appear in south-central and eastern Pennsylvania streams as riffles and rocky impediments to small water craft. Many Susquehanna River canoeists are familiar with scraping their hulls and forced portages over the "rocks of summer." In many reaches of the Susquehanna River, hard, erosion-resistant quartzitic rocks are sufficiently well exposed to allow one to cross the riverbed without becoming significantly wet.

In another area on the Susquehanna, described herein in the article "River on a Rampage," an unusually scenic and photogenic assemblage of rocks becomes accessible for the adventurous hiker during the summer. At Conewago Falls, south of Three Mile Island, diabase, an igneous rock, underlies and impedes the Susquehanna's flow as the normal bed of the river is constricted to 20 percent of its upstream width. The diabase is here pocked by uncounted numbers of large and small potholes. There are also many large blocks containing potholes, some large enough to allow adult persons to crawl from bottom to top. The river-sculpted shapes in the diabase include bowls and tubs in which to sit, as well as wave and ripple-like forms more commonly seen in seashore sand. Here they occur in very hard rock.

The many "rocks of summer" provide more benefits than hindrances. Fishermen use them for better foot access to offshore fishing holes. Visitors to Pennsylvania stream shores appreciate the beauty of their form. Geologists use them to interpret facets of recent and ancient earth history. Whatever is your pleasure or inclination, the "rocks of summer" provide relaxation and enjoyment when Pennsylvania rivers run low and slow.

Donald M. Hoskins

Donald M. Hoskins
State Geologist

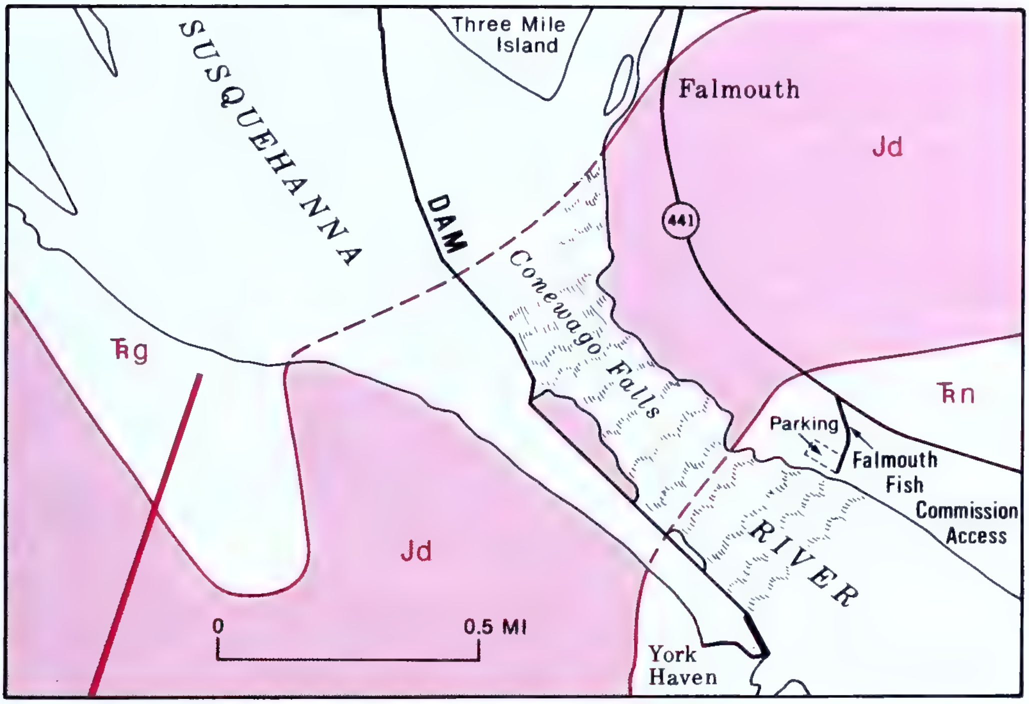
RIVER ON A RAMPAGE

by W. D. Sevon
Pennsylvania Geological Survey

Sometimes we can't see the forest because of the trees. Many of us understand that old adage through personal experience. The extraordinary may be so obvious that we overlook it. Such was the case with me and the blocks at Conewago Falls. During many traverses of the falls while studying the geology, I focused narrowly on the prominent potholes and the more subtle ripple forms eroded into the diabase. Then one day I walked the same ground searching only for the best route for a field trip. Suddenly, I noticed the blocks. They are enormous! Blocks of diabase bigger than automobiles litter the surface. And they definitely have been moved. But how? Certainly not during a normal flood of the Susquehanna River. Visions of Washington State's famous channeled scablands jumped to mind. Thus began another adventure in the geology of Pennsylvania.

GEOLOGIC SETTING. A Jurassic-age diabase sill in northwestern Lancaster County, Pennsylvania, just south of Three Mile Island (Figure 1), is made up of a tough, erosionally resistant rock that forms the bed of the Susquehanna River in the area of the low Conewago Falls. The lithologically homogeneous diabase separates into slabs along parting planes that have a low (<10 degrees) north dip and a spacing generally between 2 and 5 feet. These partings parallel the bedding dip of local Triassic-age bedrock. The diabase is broken also by joint planes that are oriented more or less northeast-southwest and northwest-southeast. The joints are variably but widely spaced. The diabase is bounded on top and bottom by hornfels and separates sandstones, siltstones, and shales of the Triassic-age New Oxford Formation (below) and Gettysburg Formation (above). Conewago Falls is a popular fishing area entered through the Falmouth Fish Commission Access. It is known also for potholes and other exotically sculptured forms that have been eroded into the diabase (Sevon, 1989).

For convenience, the falls is divided into three parts: right bank, left bank, and center (Figure 2). Both sides of the river have bank-marginal channels in which the diabase has been eroded several feet below the level of diabase in the near-bank and central areas. Diabase in the near-right-bank and right-bank channel areas is un-



EXPLANATION

——— – – Geologic contact (dashed where concealed) ▬ Fault

JURASSIC

Jd Diabase

TRIASSIC

TRg Gettysburg Formation

TRn New Oxford Formation

Figure 1. Location and geologic map of the Conewago Falls area.

derwater because of the dam, which funnels water to the York Haven power plant. During very low water stages, the riverbed is exposed in the central area and between the left-bank channel and the left bank itself.

This report concerns only the area between the left-bank channel and the left bank, but transported blocks are also found in the central area, and some blocks in the central area are larger than those on the left bank.

THE BLOCKS. Except for a few large areas that lack anything on the bedrock surface, the in-situ diabase near the left bank is littered with diabase clasts (Figure 3; also see cover) ranging in size from a few inches in diameter to a block that measures 36 by 15 by 5 feet. The mean size of 30 measured blocks is 19 by 11 by 5 feet. Such a block weighs almost 100 tons. The blocks are mainly tabular in shape, and their shape and size are controlled by the parting and joint planes. Thus, the very persistent parting planes keep the small dimension of the blocks generally less than 7 feet, whereas the other dimensions are quite variable.

Many of the blocks have potholes, and it appears that the potholes were eroded before the blocks were moved. All of the blocks show some rounding of their edges so that sharp corners are rare, but there appears to have been no significant erosion of the blocks since they were moved to their present positions. There are many smaller diabase clasts that have diameters of 4 feet or less. These smaller clasts generally appear more rounded than the large blocks, but they have not been studied.

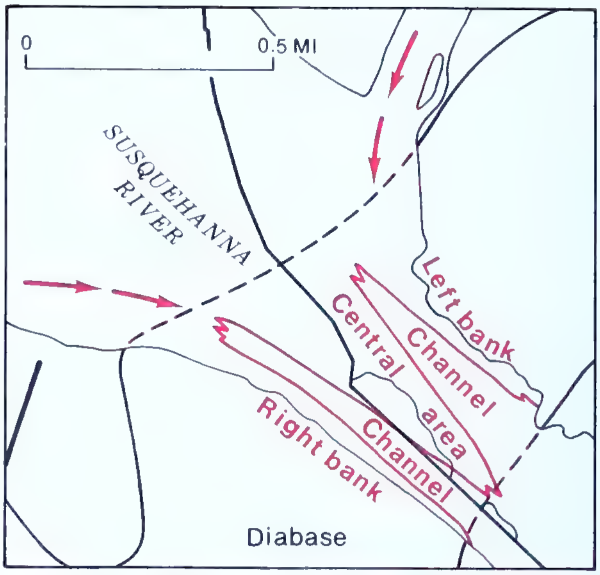
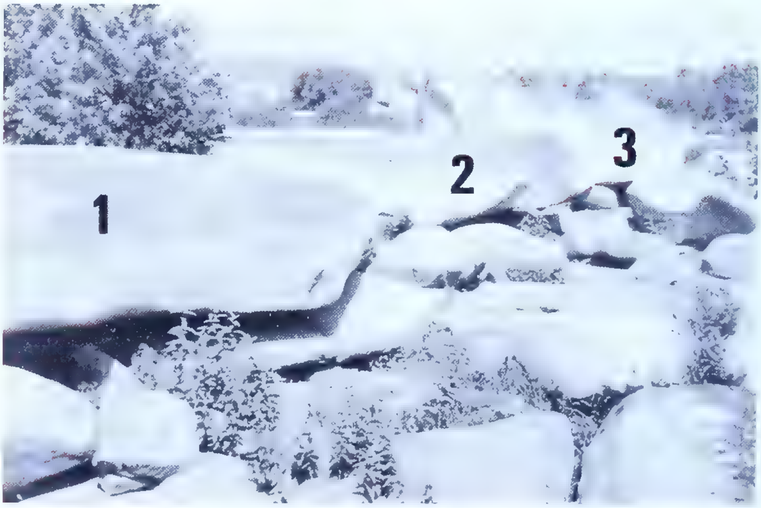


Figure 2. Map of Conewago Falls showing the general location of channels and rock areas.

Figure 3. Several large diabase blocks resting on smaller blocks at Conewago Falls. Upstream is at the back of the photograph. Block sizes are as follows: (1) 23 by 6–16 by 3 feet; (2) 23 by 6 by 3 feet; (3) 13 by 6 by 6 feet.



Because of their tabular shape, most of the larger blocks probably moved by sliding. However, a few blocks are more equant in shape, and some have definitely rolled (Figure 4). Except for a small number of blocks that have moved only a few inches from determinable original positions, the distance of transport of individual blocks is unknown. It is assumed that blocks present on the surface have been transported no farther than the distance between a specific block and the upstream edge of the diabase outcrop and not from a similar diabase sill 5 miles upstream.

TRANSPORT MECHANICS. Fluvial movement of blocks the size of those at Conewago Falls requires the energy imparted by very high discharge. A calculation using an equation from O'Connor (1993)

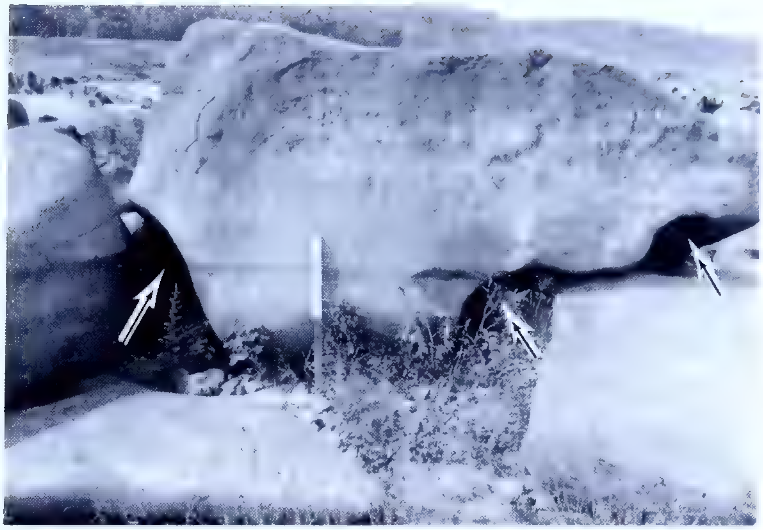


Figure 4. A large (13 by 10 by 6 feet), irregularly shaped block has rolled at least 180 degrees, as indicated by the fact that the potholes (arrows) eroded in it are upside down. Upstream is at the back of the photograph. Intervals on the scale are 50 cm.

yields a required flow velocity of about 32 ft/s (feet per second) to move a block that has an intermediate axis of 11 feet. Some understanding of what this means is gained by considering Susquehanna River flow during tropical storm Agnes in 1972. During that flood, maximum flow velocity at Harrisburg, 13 miles upstream from Conewago Falls, was 8 ft/s. The river at Harrisburg is approximately the same width as it is just north of Conewago Falls. At the falls, the river narrows to about half of its upstream width. This narrowing will cause flow velocity increase in order to accommodate the discharge, but the amount of increase would not be enough to cause movement of the large blocks during a flood equivalent to that of 1972, the flood of record. It appears that a special event is required to produce the extraordinary flow velocities.

OUTBURST HYPOTHESIS. During the Pleistocene, at least one but possibly two glaciers impinged upon Bald Eagle Mountain in the area between Lock Haven and Williamsport. The ice dam formed by this impingement blocked the West Branch Susquehanna River and created glacial Lake Lesley. This lake could have had an area of at least 704 square miles and a volume of 26 cubic miles at its maximum size (Figure 5). The natural lake drain was presumably southwest into the Juniata River drainage at Dix on the Blair-Centre County line.

During deglaciation, ice to the south of Bald Eagle Mountain would have melted gradually, and the ice front would have retreated northward. Eventually, only a narrow ice dam at the east end of Bald Eagle Mountain would have contained Lake Lesley. The pressure of the lake water could have caused catastrophic failure of the ice dam with a resulting outburst of water that might have been over 600 feet deep at the point of outburst. The course for this water would have been down the Susquehanna River.

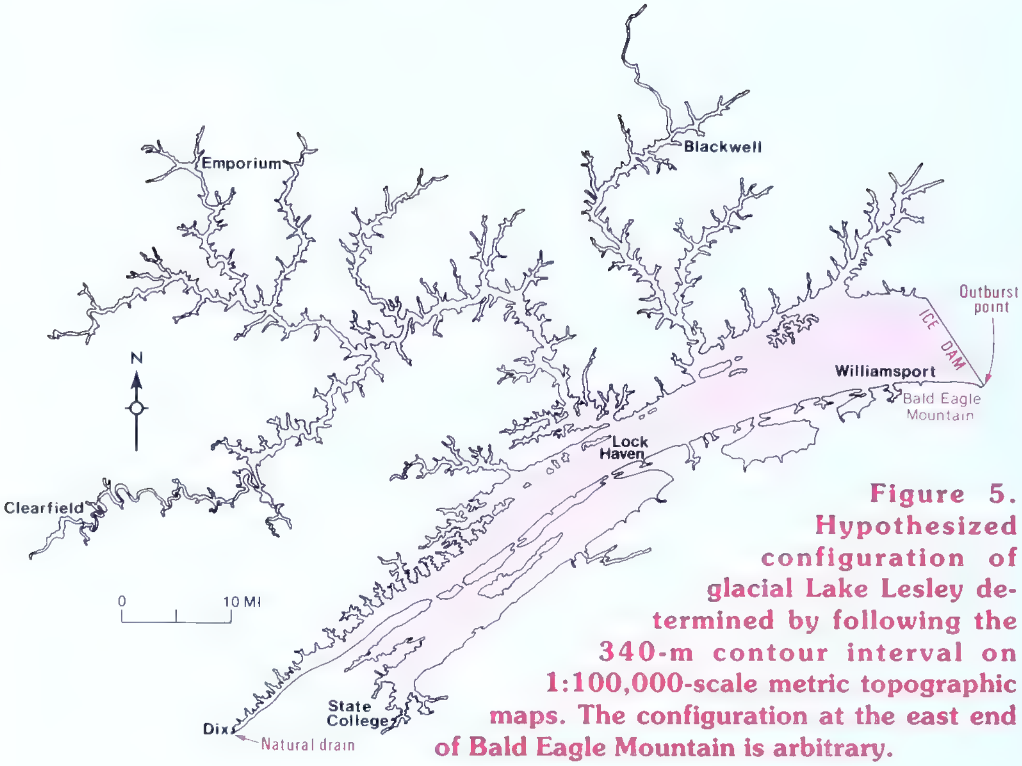


Figure 5. Hypothesized configuration of glacial Lake Lesley determined by following the 340-m contour interval on 1:100,000-scale metric topographic maps. The configuration at the east end of Bald Eagle Mountain is arbitrary.

During its downstream journey, the outburst water would have spread out and decreased in depth and flow velocity in the many wider, low-elevation areas adjacent to the main channel. However, its momentum would have been regained at each constriction, particularly the water gaps in Berry, Peters, Second, and Blue Mountains, as well as Conewago Falls.

At Conewago Falls, where the valley narrows within a few hundred feet to half its upstream width (Figure 1), discharge would have been maximized, and water depth may have exceeded 100 feet. The violence of extreme turbulence would have been concentrated in the two bank-marginal channels, and erosion of diabase would have been severe. Material from these channels presumably rests underwater downstream from the diabase sill. Higher flow velocity, but less turbulence, in the central area would have moved the largest loose blocks but would have done less erosion. All in all, it would have been an extraordinary event.

Similar erosion and transportation of debris would have occurred at the other up-river constrictions. However, the rocks that cause those constrictions are more thinly bedded, have more closely spaced joints, and normally do not produce clasts larger than small boulders. These clasts can be transported by smaller event floodwaters and are thus not recognizable as being related to an extraordinary event. This hypothesized outburst flood could also have contributed significantly to erosion of the schists in Holtwood gorge farther downstream from Conewago Falls (Thompson, 1988).

The ice dam that created Lake Lesley would have existed during one or two pre-Illinoian glaciations. An outburst caused by catastrophic failure of such a dam might have occurred several times if the glacier margin advanced and created a new ice dam following an outburst. Neither of the younger glaciers (Illinoian and late Wisconsinan) moved far enough south into Lycoming County to create a similar ice dam. During these latter glaciations, periglacial activity and deposition of outwash materials would have obscured or destroyed any evidence of earlier catastrophic flooding in most places along the margins of the Susquehanna River. Only at Conewago Falls has the evidence remained undisturbed for hundreds of thousands of years, because no subsequent floods have been large enough to move the blocks.

VISITING CONEWAGO FALLS. If you are interested in evaluating these features for yourself, take a pleasant walk sometime when the water is low. Conewago Falls is approached by walking north along the riverbed from the parking lot of the Falmouth Fish Commission Access just off Pa. Route 441 south of Three Mile Island. The diabase surface of the near left bank is exposed when the river stage is about 4 feet at Harrisburg, and the center area can be reached on foot when the Harrisburg river stage is 3.5 feet or lower. The sill extends from just north of the parking lot to north of the third up-river power line. A trail paralleling the river in the woods on the left bank simplifies returning to the parking lot.

With its potholes, ripple forms, and blocks, Conewago Falls has much to offer as evidence of the erosional activities of the Susquehanna River. The features also demonstrate the relationship between rock characteristics and erosional products. And, who knows, you may see something that others have missed!

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COALBED METHANE: NEW ENERGY FROM AN OLD SCOURGE?

by A. K. Markowski
Pennsylvania Geological Survey

The prospect of extending the lifespan of Pennsylvania's natural gas reserves should pique the interest of energy seekers of today and the future. Coalbed methane, an abundant natural gas in Pennsylvania, and generally considered a scourge to mankind, has been largely overlooked and misunderstood as a resource. It is widely known that methane has caused mine explosions and suffocation accidents throughout the world's coal regions for generations, making it a historical scourge. In addition, coalbed methane is now recognized as one of the world's major greenhouse gases, making it a modern-day scourge as well. Coal is attractive in Pennsylvania as a multiple resource; it is a source of fuel, coke (for steel manufacturing), and a chemical feedstock, as well as being a source and reservoir for methane. The removal and capture of methane prior to coal mining enhances coal resources by reducing accidents and providing an additional fuel supply.

ENVIRONMENTAL CONCERN AS A STIMULUS TO DEVELOPMENT. Methane comprises 18 percent of the world's greenhouse gases and is second only to carbon dioxide in its contribution to global warming (Clark, 1989), yet it has 20 to 30 times the heat-trapping capacity of carbon dioxide (Roane, 1990). As an energy source, coalbed methane rivals conventional natural gas in composition and heating value and lacks nuisance gases such as carbon monoxide, nitrogen oxides, and sulfur compounds. Heating values average 1,000 Btu/ft^3 (British thermal units per cubic foot) (Decker and others, 1986). With the advantage of being an energy source and with the added benefits of removing an ancient and modern scourge from the world environment, coalbed methane should attract the interest of those producing natural gas or seeking future energy resources.

HISTORY. As early as 1802, the English inventor William Murdock disclosed how coal gas (then known as firedamp) could be removed easily and burnt as a light source (Decker and others, 1986). This colorless, odorless, and nonpoisonous gas has been produced in the United States since the early part of the century, and production has occurred from the Pittsburgh seam in the Northern Appalachian coal basin since the 1930's, but generally the gas has been vented to the atmosphere. Multidisciplinary work by the United States Department of Energy in the late 1970's spurred new interest in the direct use of coalbed methane as a natural gas resource.

METHANE GENERATION AND COMPOSITION. Methane is generated in two stages of coalification: (1) the microbial decomposition of plant material (composting), mainly cellulose and lignin; and (2) the coalification of plant material after burial (lithification). In the latter stage, a complex series of chemical reactions is catalyzed by increased temperature and pressure. The primary component of coalbed gas, as determined by gas chromatography, is the simplest and most stable hydrocarbon molecule, methane—thus the name *coalbed methane*. Trace amounts of relatively heavier hydrocarbons such as ethane, propane, butane, pentane, associated isomers, and ethylene and propylene are common (Kim, 1974). Other common components of coalbed gas include oxygen, argon, nitrogen, carbon dioxide, and occasional trace amounts of hydrogen, helium, and carbon monoxide.

RESERVOIR CHARACTERISTICS. A coal seam is both the source and the reservoir rock for coalbed methane. A seam can hold two to three times as much gas as a conventional sandstone reservoir, owing to the large internal surface area of coal, over 1 billion square feet per ton, and the very tight packing of methane molecules (Kuuskraa, 1989). Gas is stored in coal in one of three states: (1) as adsorbed molecules on the micropore (microscopic pore) surfaces, usually retained by hydrostatic pressure; (2) as free gas within the pores and fractures; and (3) as a solute in formation water in the coalbed (Rightmire, 1984).

GAS MOVEMENT. Because methane is adsorbed on the internal surfaces of the coal matrix, it must first be desorbed before the gas can move to the well bore (Figure 1). Release is facilitated when dewatering of the coalbed decreases hydrostatic pressure, allowing the gas to diffuse through the matrix and micropores into small fractures (cleats) and, finally, into larger scale fracture systems. The dominant cleat, or face cleat, is in most cases a continuous, planar, smooth-sided fracture perpendicular to layering. The subordinate cleat, or butt (end) cleat, is a short and discontinuous fracture that terminates against the face cleat at approximately 90 degrees. These are thought to have formed in response to coalification processes and local structural forces (Diamond and others, 1986). Interest in gob gas is also increasing in Pennsylvania. During long-

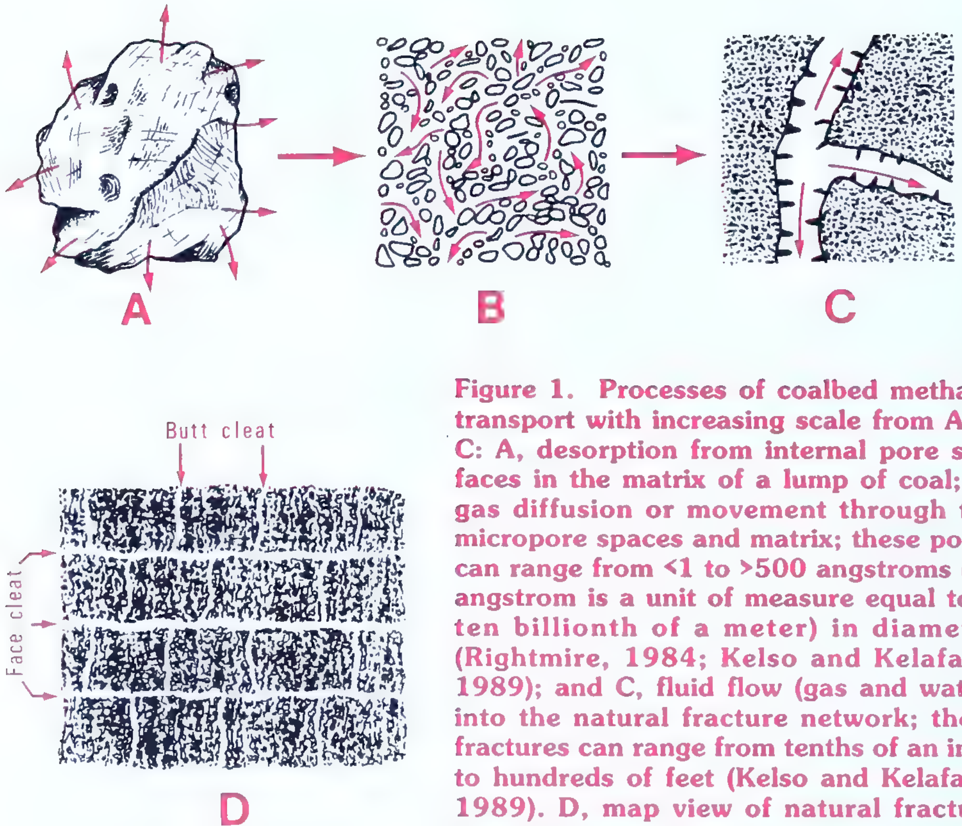

Figure 1. Processes of coalbed methane transport with increasing scale from A to C: A, desorption from internal pore surfaces in the matrix of a lump of coal; B, gas diffusion or movement through the micropore spaces and matrix; these pores can range from <1 to >500 angstroms (an angstrom is a unit of measure equal to 1 ten billionth of a meter) in diameter (Rightmire, 1984; Kelso and Kelafant, 1989); and C, fluid flow (gas and water) into the natural fracture network; these fractures can range from tenths of an inch to hundreds of feet (Kelso and Kelafant, 1989). D, map view of natural fracture (cleat) network showing face and butt cleats (Wicks and Zuber, 1989).

wall mining, the *gob*, or fractured strata above the coalbed, is designed to collapse after the coal has been removed. The gob zone can retain enough gas for capture, and the gas can be used if it is not mixed with ventilation air from the mine.

UTILIZATION. Natural gas from coalbed methane reservoirs can be used in the same ways as natural gas from more conventional reservoirs, including (1) direct flow into natural gas pipelines; (2) use as a boiler fuel in gas turbines to generate electricity at cogeneration plants; (3) use as a chemical feedstock for methanol, ammonia, and other chemicals; and (4) use as a raw material for the production of liquefied natural gas (LNG) and gas products (Kim and Deul, 1986). Another application is *cofiring*, in which natural gas and coal are burned together to utilize coals that are marginally compliant with clean air laws. Levels of sulfur dioxide and nitrogen oxide can be reduced substantially by cofiring up to 20 percent natural gas in a coal-fired boiler (Makansi, 1989). Coalbed methane should perform even better than natural gas in cofiring applications because of its reduced sulfur and nitrogen levels.

In addition, premining degasification of a coal seam and methane capture by vertical boreholes can have a significant positive effect on mining activities. Immediate benefits to the mining community include decreased risk of methane explosions, increased productivity, and reduced costs associated with gassy mines.

RESOURCE ESTIMATES. In 1988, West Virginia, Alabama, Virginia, and Pennsylvania produced more than 35 MMcfgpd (million cubic feet of gas per day) of methane emissions. According to Trevits and others (1991), 294.9 MMcfgpd was vented to the atmosphere from 487 deep coal mines in the United States in 1988. With an estimated 50 percent effective recovery of these emissions, approximately 150,000 homes could be heated per year. The deepest part of the Northern Appalachian coal basin is located in southwestern Pennsylvania and northwestern West Virginia, where the greatest number of coals are found in a vertical section (Kelafant and others, 1988). Exploration costs for the dominantly Pennsylvanian age eastern coals should be relatively low owing to the shallow depth (less than 3,000 feet) and characteristically thin beds (less than 12 feet thick) (Decker and others, 1986). The estimated resource of coalbed methane for southwestern Pennsylvania and northwestern West Virginia is 51 Tcf (trillion cubic feet) of gas in place (Kelafant and others, 1988). This resource could potentially heat 70 million homes for a year, assuming 50 percent effective recovery.

CURRENT RESEARCH AND EXPLORATION. The Pennsylvania Geological Survey has been investigating coalbed methane for about five years. In an initial reconnaissance study of the Main Bituminous field in southwestern Pennsylvania (see back cover), Markowski (in review) concurred with workers on earlier studies that there is a direct correlation between the depth of a coal seam and its gas content. As part of this reconnaissance study, graphs and tables showing depth and thickness versus total gas content, graphs showing time versus cumulative gas content, and statistical studies on emission rates were prepared and are available on open file at the offices of the Pennsylvania Geological Survey.

A more recent regional study of coalbed methane resources in the Northern Appalachian coal basin was supported by the Gas Research Institute (GRI) of Chicago and conducted in association with the West Virginia Geological and Economic Survey (Schwietering and others, 1991). In the study, two stratigraphic units thought to have the greatest coalbed methane potential in southwestern Pennsylvania were identified (Figure 2). Some of the geologic factors cited as affecting coalbed methane production and development include (1) depositional and stratigraphic controls; (2) structural controls, tectonic history, and natural fracture systems; and (3) hydrologic controls.

The most recent work at the Survey involves a second phase of the GRI-funded Pennsylvania-West Virginia study (Oldham and

SYSTEM	SERIES	GROUP OR FORMATION	IMPORTANT COALBEDS
PERMIAN-PENNSYLVANIAN		Dunkard Group (part)	Washington
			Waynesburg "A"
			Waynesburg
PENNSYLVANIAN	Upper	Monongahela Group	Uniontown
			Sewickley
			Redstone
			Pittsburgh
		Conemaugh Group	Upper Bakerstown
			Lower Bakerstown
			Mahoning
	Middle	Allegheny Group	Upper Freeport
			Lower Freeport
			Upper Kittanning
			Middle Kittanning
			Lower Kittanning
			Clarion/Brookville
		Pottsville Group	Upper Mercer
			Lower Mercer
			Quakertown
	Lower		Sharon
MISSISSIPPIAN	Upper		

Figure 2. General coal stratigraphy and the two stratigraphic intervals (color) having the greatest coalbed methane potential in southwestern Pennsylvania.

others, in review). Major goals of this phase of the project are to map the lesser known stratigraphy of the deeper Allegheny Group coals and associated sandstones, identify coals from regional cross sections, and create coal and sandstone isopleth, isolith, and isopach maps. This information will be used to identify areas of methane potential. Also, ongoing Survey and industry drilling projects provide additional information for the coalbed methane data base.

Exploration and testing by industry are ongoing; however, commercialization of this gas in Pennsylvania has only recently begun with the O'Brien Methane Production Company sale of coalbed methane from Indiana County. Optimism prevails concerning future development. On a national level, coalbed methane is commercially developed in coal seams in the San Juan basin of Colorado and New Mexico and the Black Warrior basin of Alabama. Activity is growing in the Central Appalachian coal basin of Virginia as well.

REGULATORY ISSUES. Legal ownership of coalbed methane is still contested, despite a 1983 court case in which it was concluded that "any gas found within a coalbed must necessarily belong to the owner of the coal!" (Johnson, 1992). Until clear ownership is established, any successful development of coalbed methane will likely depend on agreements among the oil and gas developer, the landowner, and the coal company. Federal legislation proposed to stimulate development includes the concept of forced (involuntary) pooling. Modeled after Virginia's 1990 oil and gas law, forced pooling requires the owners to pool and develop their lands as a unit prior to ownership determination.

CONCLUSION. One of the challenges of current researchers is to learn more about coalbed methane so that we can turn this former waste product that is a mining and environmental hazard into a valuable resource. With this in mind, economic, legal, and environmental factors will ultimately determine the fate of this currently wasted and much maligned, but valuable, resource.

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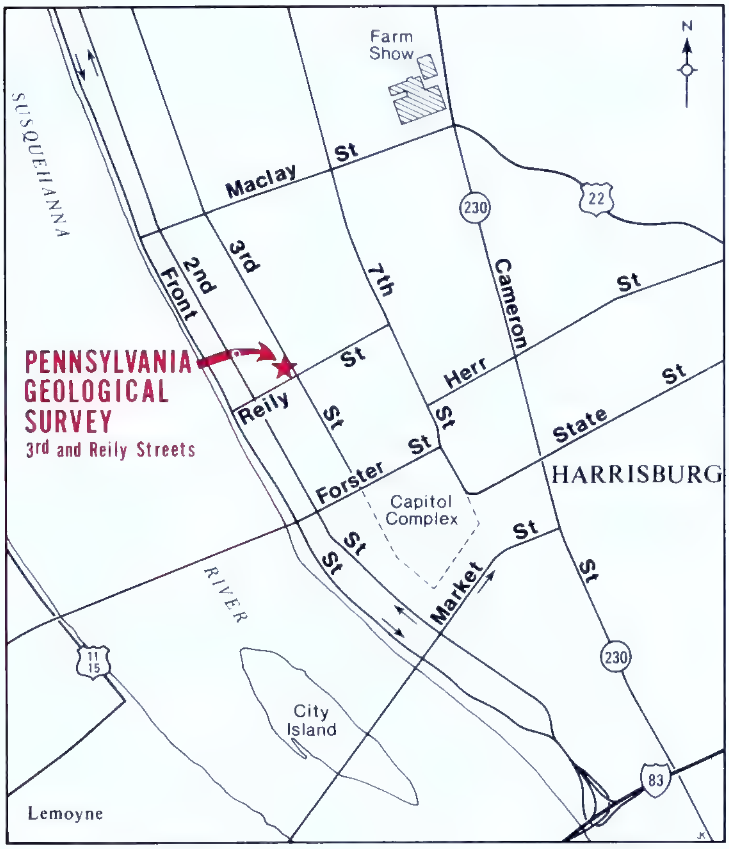
ANNOUNCEMENTS

The Survey Moves to Third and Reily Streets

After nearly two decades of occupancy on the eighth and ninth floors of the Executive House in downtown Harrisburg, the Pennsylvania Geological Survey has moved uptown to facilities in a building at the corner of Third and Reily Streets, about 20 blocks north of its previous location. The building (see photograph) once housed a religious publication and retail business. This former enterprise, now gone for over 20 years, provides the building with its colloquial name: "The Evan(gelical) Press Building." The building provided temporary quarters for the Survey for a few months in 1972 following the destruction of its offices as a result of flooding caused by Hurricane Agnes. It was in this building that the Survey began to rebuild its physical facilities that support public service through geologic mapping and information dissemination.

Evangelical Press Building at the corner of Third and Reily Streets, Harrisburg. The Survey occupies the second floor of the building. The front entrance, shown here, is on Reily Street.

Location of the present Survey quarters in Harrisburg.

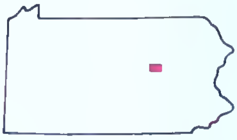


The building has been for many years the location of the central laboratories of the Department of Environmental Resources as well as other Department offices. The Pennsylvania Geological Survey now occupies the entire second floor of the building. Our frequently used library, map collection, and aerial photography files are located near the main entrance and are easily accessible from Reily Street, the entrance seen in the photograph. Visitors are welcome to use the library and its collections and to tour our new offices. Visitors must use the telephone affixed to the building near the main entrance to gain access, because the entire building is protected by a security system that provides safety and quality control for the thousands of environmental samples processed by Department laboratories on the building's first floor and basement.

The Pennsylvania Geological Survey will temporarily occupy these "new" quarters until offices and laboratories are constructed as part of a new Commonwealth building being designed to house several agencies that require laboratories in order to accomplish their missions.

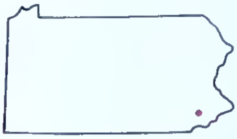
NEW PUBLICATIONS

Geology and Mineral Resources of the Washingtonville and Millville Quadrangles



The Pennsylvania Geological Survey has released **Geology and Mineral Resources of the Washingtonville and Millville Quadrangles, Montour, Columbia, and Northumberland Counties, Pennsylvania.** The report is the newest addition to a series of atlases published by the Survey that cover the geology of the northeastern part of the Appalachian Mountain section of the Ridge and Valley physiographic province. The 51-page text contains discussions of the structural geology, environmental geology, and economic resources of the area. Two full-color plates showing bedrock and surficial geology at 1:24,000 scale accompany the text. Atlas 154cd, by John H. Way of Lock Haven University, is available for $15.85, plus 6 percent state sales tax for Pennsylvania residents, from the State Book Store, 1825 Stanley Drive, Harrisburg, PA 17103–1257. Orders must be prepaid; please make checks payable to *Commonwealth of Pennsylvania.*

Guide to the Geology of Valley Forge National Historical Park



A new, completely revised edition of Park Guide 8, **Valley Forge National Historical Park, Montgomery and Chester Counties,** was recently released by the Pennsylvania Geological Survey as part of the "Trail of Geology" series. The park guide was published in honor of the centennial of the Pennsylvania state park system, which began in 1893 with the opening of Valley Forge State Park (now a federal park). The author, C. Gil Wiswall of West Chester University, describes the rock formations found in the park and explains the geologic history of the area. A centerfold map shows simplified geology and the locations of sites described in the text. The two-color, 13-page booklet is free and may be obtained at the park office or by writing to the Pennsylvania Geological Survey, P. O. Box 8453, Harrisburg, PA 17105–8453.

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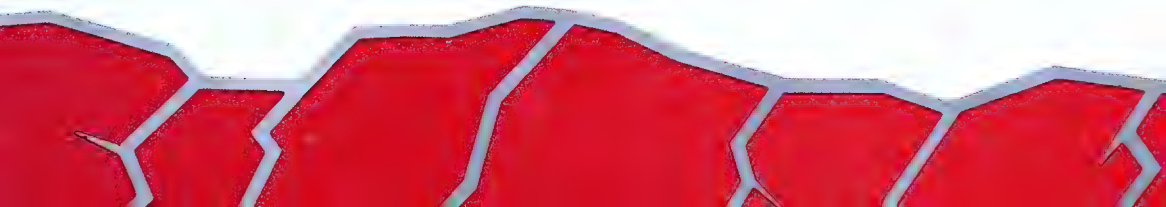

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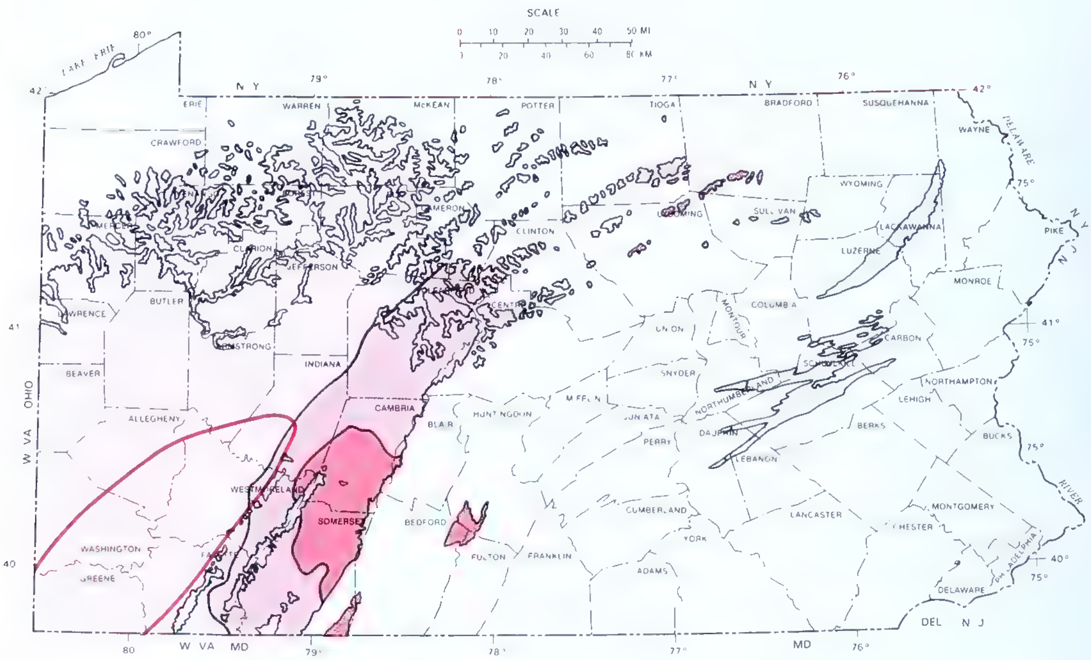

EXPLANATION

BITUMINOUS FIELDS

☐ High-volatile bituminous coal

▨ Medium-volatile bituminous coal

🟥 Low-volatile bituminous coal

ANTHRACITE FIELDS

☐ Anthracite

▨ Semi-anthracite

Outline of study area for coalbed methane project (see article on page 8)

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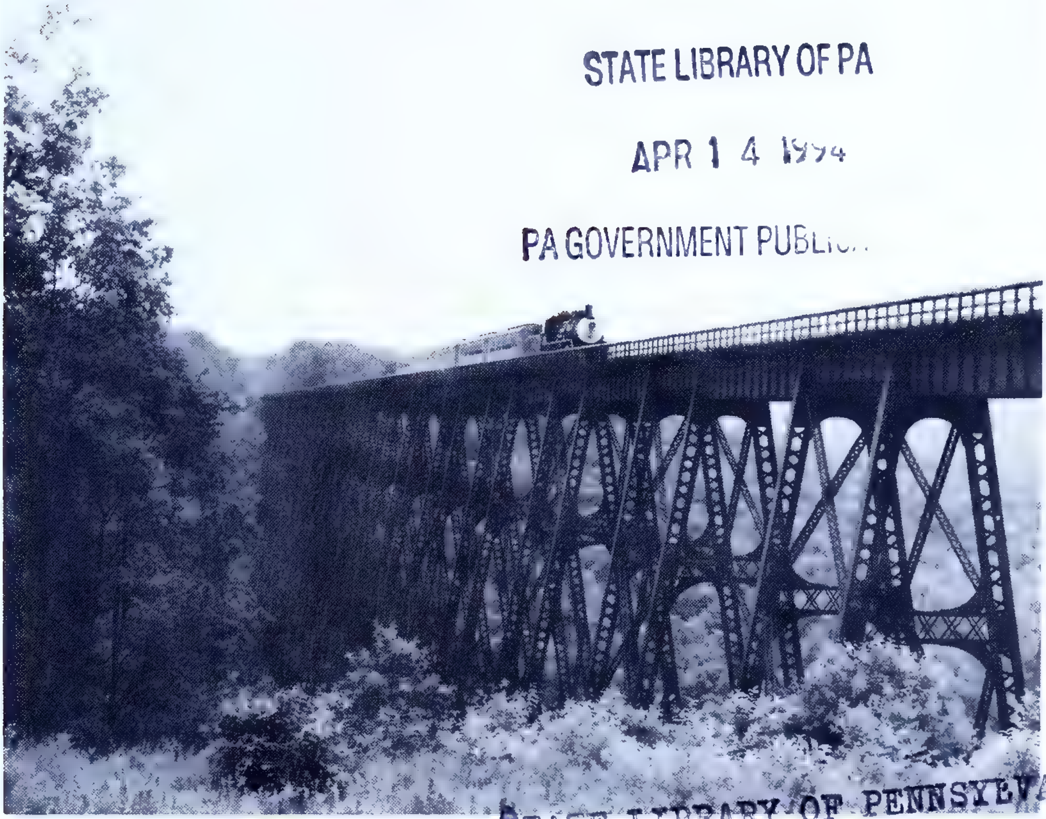

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ON THE COVER

Steam-locomotive and excursion cars of the Knox, Kane, Kinzua Railroad crossing the steel Kinzua Viaduct (see article on page 2). View is from the north side of the Kinzua Creek valley. Photograph by J. D. Inners.

PENNSYLVANIA GEOLOGY

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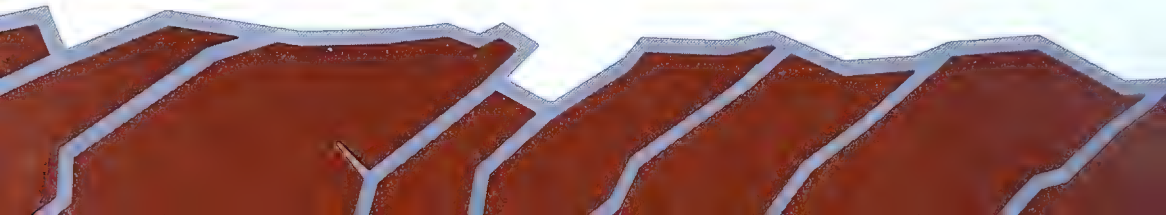

STATE GEOLOGIST'S EDITORIAL

Of What Men Choose to Forget

The title is a line from a poem by T. S. Eliot that refers to the inevitability of damaging floods like those reported so extensively in the public media during the past summer. To earth scientists, these events, as well as most other natural catastrophic events, are to be expected and endured inasmuch as they are cyclically repetitive and exceed most human ability for prevention. They are and should be understood as a reality of nature and, by understanding, possibly ameliorated.

Yet many do not understand the nature of catastrophic events and look to science for solutions. Scientists, in their hubris, generally have offered technological solutions, but have forgotten that education perhaps better serves humanity than does a technology. When the technology is overwhelmed, such as with breached or overtopped levees, confidence in such solutions (and science) is lessened. For many human problems, particularly natural geologic hazards, the only real solution for the affected person is to move. Damage and destruction of human constructions is inevitable when they are placed in the paths of natural catastrophic phenomena such as on the floodplains of rivers. To not understand their inevitability is to attempt to escape some basic realities of life.

Continued population growth will place greater stress on natural systems, and more damage will occur unless earth scientists offer more education and fewer "solutions." Changing society's attitude from one that desires to avoid natural hazards by quick technological fixes to one of understanding natural catastrophic events will not be easy. Yet I feel that we must make the effort if we are to use our scientific understanding of the earth's natural forces for the benefit of all. If we who understand do not choose to provide a basic understanding of earth systems, we fail in the proper use of our knowledge. We need to continually remind our fellow humans "of what men choose to forget."

Donald M. Hoskins

Donald M. Hoskins
State Geologist

Carrying the Sky on Its Back: The Historical Geography of the Kinzua Viaduct

by William E. Kochanov, Jon D. Inners, and Joseph M. Tarantino
Pennsylvania Department of Environmental Resources

INTRODUCTION. "Economics + geology + engineering = railroads!" This was the formula that led to a profusion of great civil-engineering works throughout the world during the latter half of the nineteenth century and early part of the twentieth. Economics created the incentives for construction of a railroad between two points, geology formed the natural barriers, and engineering overcame these barriers. The most famous example of this formula in Pennsylvania was the railroad conquest of the Allegheny Front by J. Edgar Thompson's Horseshoe Curve in 1854. Not far behind in Pennsylvania's railroad lore, however, was the vaulting of the Kinzua Valley in 1882 by Adolphus Bonzano and Octave Chanute's wrought-iron Kinzua Viaduct (the viaduct was rebuilt of steel 18 years later).

A viaduct is a bridge that crosses a valley in which the width of the water course is only a small fraction of the total distance required to be traversed (Thornton, 1987). In addition to the Kinzua in McKean County, Pennsylvania boasts two of the world's other great railroad viaducts: the stone Starrucca Viaduct (1848) in Susquehanna County and the concrete Tunkhannock Viaduct (1915) in Wyoming County (Jackson, 1988; DeLony, 1993). Of these, the Starrucca and the Tunkhannock are noteworthy for their impressive strength and bulk, but neither of these renowned structures carries the sky on its back with the grace of the Kinzua.

PHYSIOGRAPHY AND GEOLOGY. Kinzua Creek rises at an elevation of 2,180 feet near Cyclone, McKean County, and, after flowing westward in an irregular sweeping curve (concave to the north) for 26.5 miles, empties into Kinzua Bay of the Allegheny Reservoir at an elevation of 1,328 feet (Shaw, 1984; see back cover). Before construction of the Kinzua Dam on the Allegheny River just east of Warren, the creek continued northwest for another 8 miles and joined the Allegheny at the now-inundated village of Kinzua.

In its course across the Allegheny High Plateau from Cyclone to the Allegheny Reservoir, Kinzua Creek has carved a broad, deep

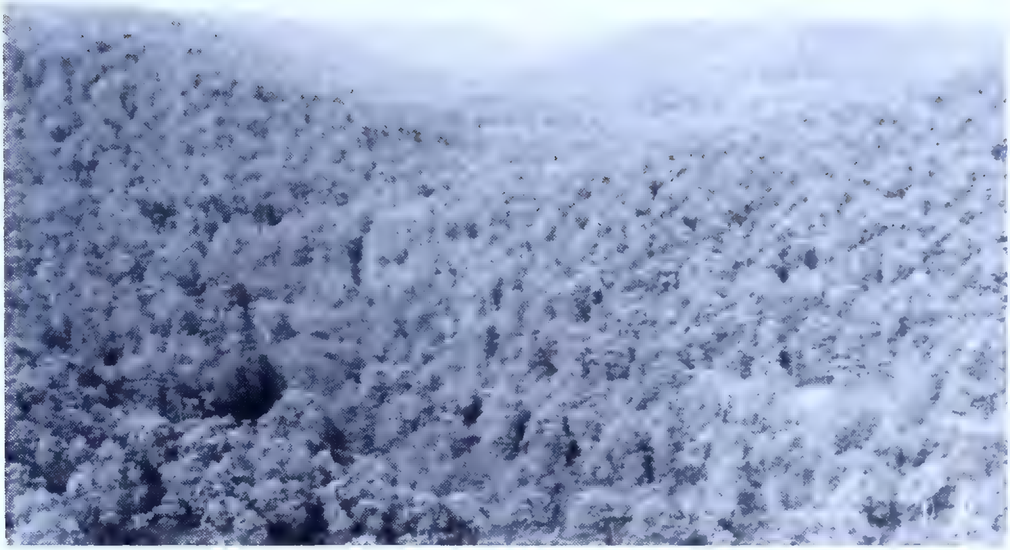

Figure 1. View of the Kinzua Creek valley and the High Plateau, looking southwest from the middle of the Kinzua Viaduct. Note the remarkable accordance and flatness of the plateau upland surface, most of which is capped by Pottsville Group sandstones. The U shape of the valley, evident in the distance, is probably due to intense colluviation in the weak, shaly Mississippian-Devonian rocks beneath the Pottsville caprock.

valley that is more than 300 feet deep at Kinzua Bridge State Park and more than 700 feet deep at the site of Kinzua village. The upland terrain on either side of this valley is remarkably flat (Figures 1 and 2), particularly on the south side where the "Big Level" forms the divide between the drainage basin of Kinzua Creek and those of the upper Allegheny and Clarion Rivers (Ashburner, 1880). This conspicuous divide, as well as most of the flat terrain bordering the stream valley, is developed mainly on resistant, subhorizontal sandstone units in the Pottsville Group of Early Pennsylvanian age (Figure 2). One of these sandstones forms the overlook within the state park. Less resistant shales and sandstones of Mississippian and Late Devonian age underlie the valleys of Kinzua Creek and its major tributaries (Figure 2). These older rock units in the Kinzua Valley are overlain by an unknown, variable thickness of Recent alluvial silt, sand, and gravel, possibly exceeding 30 feet locally.

CONSTRUCTION HISTORY OF THE TWO VIADUCTS. By the last quarter of the nineteenth century, exploitation of the abundant oil, natural gas, and bituminous coal contained in the late Paleozoic rocks of McKean County and nearby areas was proceeding at a

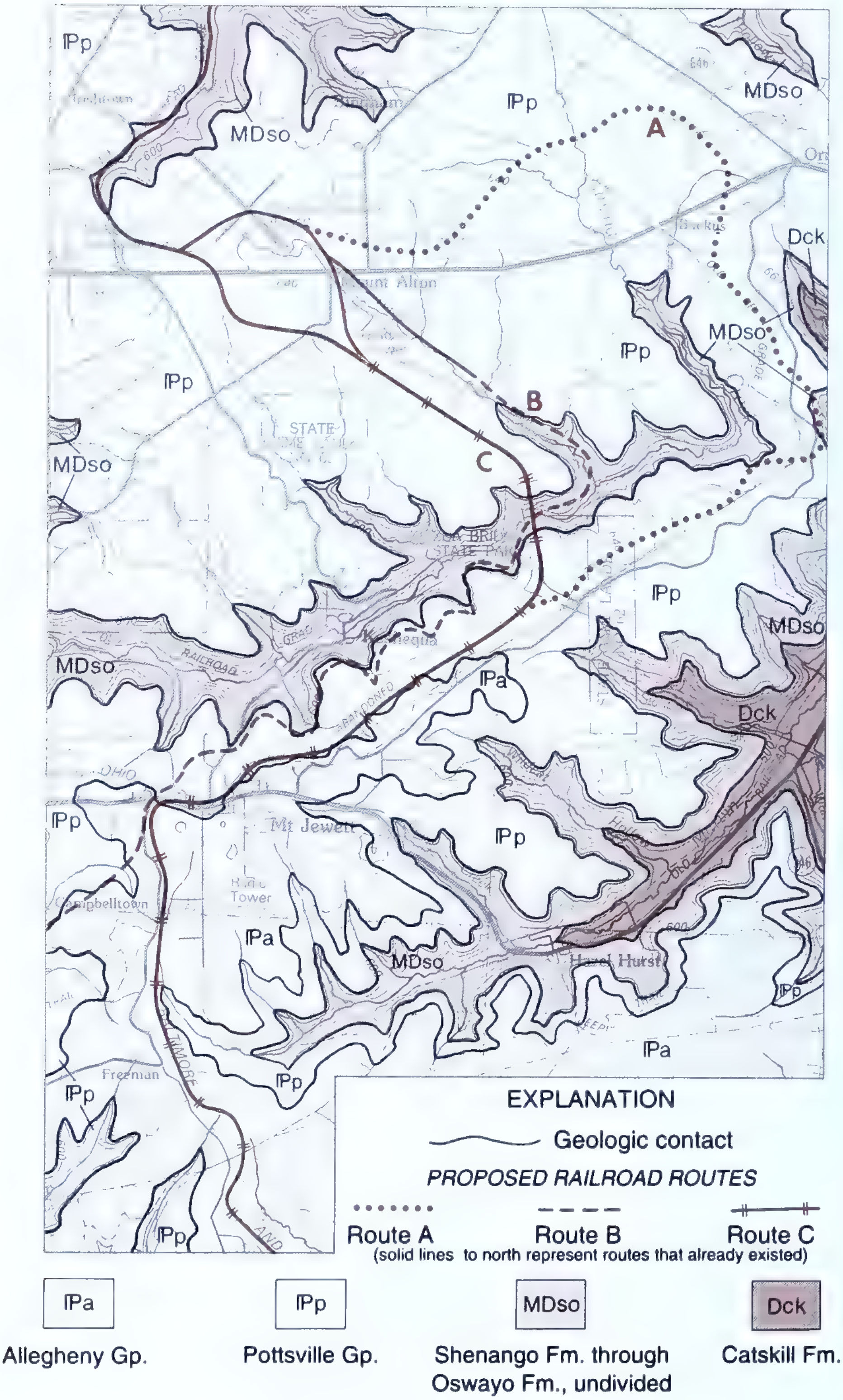

Figure 2. Geologic map of the Kinzua Bridge area (generalized from Berg and Dodge, 1981). Base map from U.S. Geological Survey Bradford 30- by 60-minute quadrangle; contour interval 20 meters. Railroad routes from The Railroad Gazette (1882a).

brisk pace. This was the era of vast railroad land holdings, and the situation in the northern tier counties of Pennsylvania mirrored that in the rest of the nation. Most important to the Kinzua story were the real-estate transactions of the Erie Railroad and its local subsidiary, the New York, Lake Erie and Western Coal and Railroad Company.

Sometime after the end of the Civil War, the Erie Railroad purchased about 27,000 acres of coal lands in Elk and Jefferson Counties 25 miles south of the site of the future Kinzua Viaduct. Economic production of coal from these large holdings was seriously limited, however, by the circuitous routes that coal trains were forced to take to both eastern (via Emporium, Pa., to Olean, N. Y.) and western (via Warren, Pa., to Buffalo, N. Y.) markets. The increasing demand for coal in western New York and the lake ports made it imperative that the Erie construct a more direct line to the new coal fields, from which it was anticipated that 3 million tons per year could be marketed (The Railroad Gazette, 1882a). Considering the railroad's existing holdings, it was clear that the best route lay directly north to the Erie main line at Carrolton, N. Y. Unfortunately, a few miles north of the midpoint of the proposed line and squarely across it lay the east-west valley of Kinzua Creek, 2,000 feet wide and 300 feet deep.

The Erie went quickly to work and created the subsidiary New York, Lake Erie and Western Coal and Railroad Company to carry out the project. General Thomas Leiper Kane (1822–1883), Civil War hero and president of the new company, and Oliver W. Barnes, its chief engineer, took on the task of constructing the railroad line from Mount Alton in McKean County across or around the Kinzua Valley and south to the coal fields in Elk County (see back cover). Chief Engineer Barnes was faced with three possible ways of traversing the Kinzua Valley (Figure 2). One was to avoid the valley entirely (line A on Figure 2); this would have extended the length of the route by 8 miles. The second was to build the track down one side of the valley, cross a 125-foot-high viaduct, and then ascend the other side (line B); but this approach would limit the weight of trains, consume more energy to run the trains, and increase the operating cost. The third (line C) was to construct a viaduct directly across the valley (The Railroad Gazette, 1882a; Thornton, 1987).

Barnes chose the third option, which resulted in the grade shown in Figure 3 for the segment of the railroad in the immediate vicinity of the Kinzua Valley. After reviewing numerous proposals for a structure across the valley, Kane and Barnes selected a wrought-iron viaduct design by the Clarke Reeves Division of the Phoenix Bridge Works of Phoenixville, Pa. The main structural design was by Adolphus Bonzano and T. C. Clarke of Clarke Reeves. Octave Chanute (1831–1910), Chief Engineer of the parent Erie

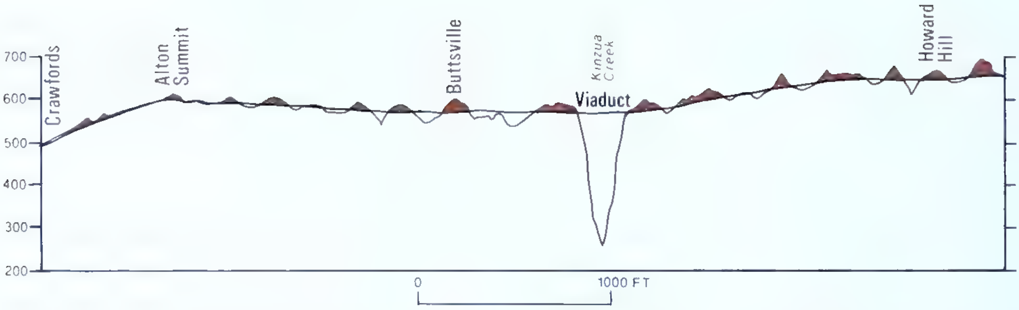

Figure 3. Final grade of the New York, Lake Erie and Western Railroad from Mount Alton to Howard Hill (now Mount Jewett) (after The Railroad Gazette, 1882b).

Railroad and already famous for his work on the Hannibal Bridge in Missouri and the New York City elevated railroad, was site engineer for the actual erection of the viaduct (The Railroad Gazette, 1882b; Clarke, 1891; Thornton, 1987). During the summer of 1881, the site was cleared, and abutments and pier foundations were constructed from 7,000 cubic yards of local Pottsville sandstone. The piers, 110 in number, extended as much as 35 feet below the alluvial floor of the valley and up to 16 feet aboveground (subsequent to completion of the second viaduct and between the years 1907 and 1933, the sandstone piers were encased in concrete) (The Railroad Gazette, 1900; Thornton, 1987; Pennsylvania Department of Environmental Resources, 1990).

Work was halted during the winter months and resumed during the spring of 1882. The erection of the ironwork structures began in April. With materials brought in by a temporary rail line, erection of the viaduct proceeded at a rate of 500 feet per month. In just 94 days, on August 25, 1882, a crew averaging 125 men completed the highest and longest railroad viaduct erected to that time at a cost of between $167,000 and $275,000 (The Railroad Gazette, 1882b; Clarke, 1891; Thornton, 1987).

The engineering statistics of the original viaduct are given in Table 1. The structure was designed to handle consolidation locomotives weighing a little over 100,000 pounds and hauling coal cars having an average capacity of 40,000 pounds (The Railroad Gazette, 1900). Early boasts that the bridge could carry the "heaviest trains at high speed" (The Railroad Gazette, 1882b) proved to be unrealistic, and trains were from the first restricted to a speed of 5 miles per hour to minimize vibrations on the rather spindly structure (Thornton, 1987).

Table 1. Engineering Statistics of the Original (1882) Kinzua Viaduct
(from Clarke, 1891; Thornton, 1987; and Jackson, 1988)

Elevation of railroad grade	2,060	feet
Length	2,053	feet
Height	301.5	feet
Width of towers	38.5	feet
Connecting spans	61	feet
Depth of girders	6	feet
Width of platform	18	feet
Gauge of railroad	4.7	feet
Inclination of pier posts	1:6	
Weight of iron	3,135,000	pounds

From the beginning, the Kinzua Viaduct served as a mecca for tourists and excursion trains. In fact, revenues from excursions to the old viaduct are reported to have offset the cost of its construction (Thornton, 1987). Nearly a century later, this public romance with the Kinzua proved to be its salvation.

The wrought-iron viaduct served well until 1900. By that time, however, the greater power and weight of locomotives, with consequent increase in total train tonnage, dictated that the viaduct be strengthened. A total reconstruction, using steel in place of wrought iron but keeping the same dimensions as the original and using the original pier footings, commenced on May 24, 1900, just 10 days after train traffic had been stopped. Steel was obtained from the Elmira Bridge Company and erected by Gratton and Jennings and Company of Buffalo. Under the supervision of resident engineer C. W. Bucholtz, Chief Engineer of the Erie Railroad, it took only four months to tear down the original viaduct and build its replacement (see front cover) (The Railroad Gazette, 1900; Thornton, 1987).

The final steelwork was placed on September 6, 1900, and the first train crossed the new viaduct on September 24. Steel replacing iron increased the weight of the structure to 6,715,000 pounds. This allowed trains with consolidation locomotives weighing 190,000 pounds and hauling cars having a capacity of 100,000 pounds each to safely cross the new viaduct, but still at reduced speeds.

LATER HISTORY: ABANDONMENT AND REUTILIZATION. Train traffic across the Kinzua Viaduct continued until June 1959, at which time the Erie Railroad abandoned the portion of its Bradford Division containing the Kinzua Viaduct. In an age when oil, not coal, was "king," hauling coal to Buffalo did not pay. The viaduct and adjacent trackage and land were sold in 1963 to the Commonwealth of Pennsylvania for a proposed state park (Thornton, 1987; Burkholder, 1993).

After several years of debate had finally established the historical and scenic value of the viaduct, Kinzua Bridge State Park was dedicated on July 5, 1975. In 1977, the viaduct was entered into the National Register of Historic Landmarks, and in 1982, in the year of its centenary, it was designated a National Historic Civil Engineering Landmark.

But merely preserving such an engineering masterpiece as the Kinzua Viaduct is like putting a fine racehorse out to pasture; it retains but a shadow of its former glory. Luckily, however, the great bridge did not long remain unused. If its usefulness to industry and commerce had come to an end, its old fascination as a tourist attraction proved to be as strong as ever.

The reuse of the viaduct started with the 1982 acquisition of Knox (Clarion County) to Kinzua Bridge trackage by the Knox, Kane, Kinzua Railroad. Then, in 1986, the Knox, Kane, Kinzua Railroad entered into an agreement with the Pennsylvania Department of Environmental Resources to lease and maintain the viaduct. After new track was laid from Mount Jewett to Kinzua Bridge and a turnaround "Y" constructed on the north side of the Kinzua Creek valley, the rejuvenated railroad ran its first tourist excursion train across the viaduct on August 7, 1987.

As a result of this imaginative cooperation between private enterprise and state government, the Knox, Kane, Kinzua Railroad now operates excursion trains to the Kinzua Viaduct from the first of June to the last day of October. A trip on the Knox, Kane, Kinzua Railroad provides an entertaining introduction to the geology of the Kinzua region, from the bedrock-controlled "Big Level" west of Mount Jewett through the numerous cuts in crossbedded Pottsville sandstone between Mount Jewett and the state park (see front cover) to the deep, incised valley of Kinzua Creek at the viaduct crossing. It also provides an unparalleled opportunity to ponder the boldness of conception, the ingenuity of construction, and the skill of workmanship that are reflected in that "eighth wonder of the world"—the Kinzua Viaduct.

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Giving the Mississippian/Devonian Boundary a Facelift

by John A. Harper
Pennsylvania Geological Survey

INTRODUCTION. There is a new face on the stratigraphy of Pennsylvania. Geologists and anyone interested in the organization of geologic time periods need to be aware that because of a growing list of paleontological evidence now believed to be indisputable, the boundary between the rocks of the Mississippian and Devonian Periods was changed in 1992.

STRATIGRAPHIC CHANGES. Stratigraphy is a branch of geology whose name means, literally, writing about layers (strata). It is the science of describing, naming, correlating, and mapping rock layers by using the physical, chemical, and biological properties of the rock such as composition, color, and fossil content. Stratigraphy is a complex science that is practiced by many geologists but completely and correctly understood by only a few. Its rules, embodied in the code of stratigraphic nomenclature (North American Commission on Stratigraphic Nomenclature, 1983), encompass such a broad spectrum that they tend to confuse the nonspecialist. Understanding and properly using them may even challenge those who feel that stratigraphy is their specialty.

Additions, corrections, and other changes in the vast nomenclature of stratigraphy occur on a regular basis. Hardly a day goes by without the naming of at least one new stratigraphic unit in a professional publication somewhere in the world. In the comment and reply sections of earth science magazines and journals, geologists argue over the merits of changing the status of stratigraphic units or using one set of names over another. "State-line fault" is a humorous, informal term used to describe the confusion that results when geologists in adjacent states apply different names or assign different geologic ages to the same set of rocks. Such confusion often upsets those whose interests are more oriented toward geologic processes, prompting the late petrologist/sedimentologist Paul D. Krynine to observe, "stratigraphy is the triumph of terminology over common sense" (Miall, 1984, p. 3).

Minor changes occur in the stratigraphic terminology of Pennsylvania on a regular basis, and currently there are numerous geologists holding conflicting views of strata included in Pennsylvania's stratigraphy. A geologist using the name Tuscarora "Formation" will find disagreement from others insisting on the more restricted name Tuscarora "Sandstone." Less common are changes in formation age, which are made when a researcher reassigns a set of rock units from one geologic age to another. Under the current rules of stratigraphy, a formation (a rock unit) cannot define an age (a time unit), nor can an age, recognized by radioactive isotopes and fossils, be used to define a formation. Although isotopes and fossils are found in rock units, rock units are basically independent of fossil and isotope data. For example, the Tuscarora Formation (or Sandstone) is Early Silurian in age. We may change the name Tuscarora Formation to Tuscarora Sandstone because the unit is composed mostly of sandstone, or to Medina Group because over many miles, the rocks change from mostly sandstones to mostly shales. However, the Tuscarora Sandstone and Medina Group maintain an Early Silurian age because of isotope and/or fossil evidence.

WHEN FOSSILS TELL A DIFFERENT STORY. What happens when isotope or fossil evidence disagrees with the previously established age of the rock units? Then we must change the age to agree with the new data. This happened recently in Pennsylvania. An increasing number of new fossil discoveries indicate that certain formations currently considered to be Early Mississippian in age are actually Late Devonian in age. Although there are no isotope data to absolutely dispute or substantiate the new claim, the data from fossils carry enough weight to require us to reset the traditional boundary between the Mississippian and Devonian in Pennsylvania and adjacent states.

Geologists traditionally place the boundary between the Mississippian and Devonian Periods at the base of the Cussewago Formation of northwestern Pennsylvania and its equivalents throughout the state (Figure 1). However, the position of this boundary "has provided much lively controversy during the last 100 years" (deWitt and McGrew, 1979, p. 15). Early in this century, some geologists considered the Cussewago-equivalent Murrysville sand in the subsurface of southwestern Pennsylvania to be within the Devonian Period, even though the Cussewago maintained its status as a Mississippian-age formation. At other times, geologists considered the boundary to lie several hundred feet below the Murrysville. Most of this confusion resulted from poor correlation of strata thousands of feet below the surface, encountered only in scattered areas of oil and gas well drilling and known only through chips of rock taken from the hole by the driller. Considering the techniques available at the time, it is amazing how much our geological predecessors accomplished.

In the 1960's, it became evident that some of the rocks assigned an Early Mississippian age in Ohio and Michigan might be Devonian in age, based on fossil plant spores. One spore with the unwieldy name of *Hymenozonotriletes lepidophytus* Kedo (Figure 2A) occurs in rocks ranging from the upper part of the Ohio Shale, traditionally considered Late Devonian in age, through the lower part of the Mississippian Cuyahoga Formation. Some controversy ensued when one geologist claimed that this fossil indicated a Devonian age for all of the rocks in the sequence and another argued that other data contradicted that claim (deWitt, 1970). Further investigation of the total spore content of these rocks led Eames (1974) to conclude that the Mississippian/Devonian boundary should be placed at or near the top of the Berea Sandstone (Figure 1). Because the Berea lies stratigraphically higher (i.e., is geologically younger) than the Cussewago and its equivalents, the Cussewago and its equivalents logically must be of Devonian age as well.

More recent evidence for raising the roof on the Mississippian/Devonian boundary is from brachiopod and arthropod fossils. It has been known for many years that the Berea-equivalent Corry and Knapp Formations of northwestern Pennsylvania and parts of the Price Formation of West Virginia contain fossils of the brachiopod *Cyrtospirifer* (Figure 2B), called "*Spirifer disjunctus*" in almost all pre-1950's publications. It also occurs in the "Cussewago Sand-

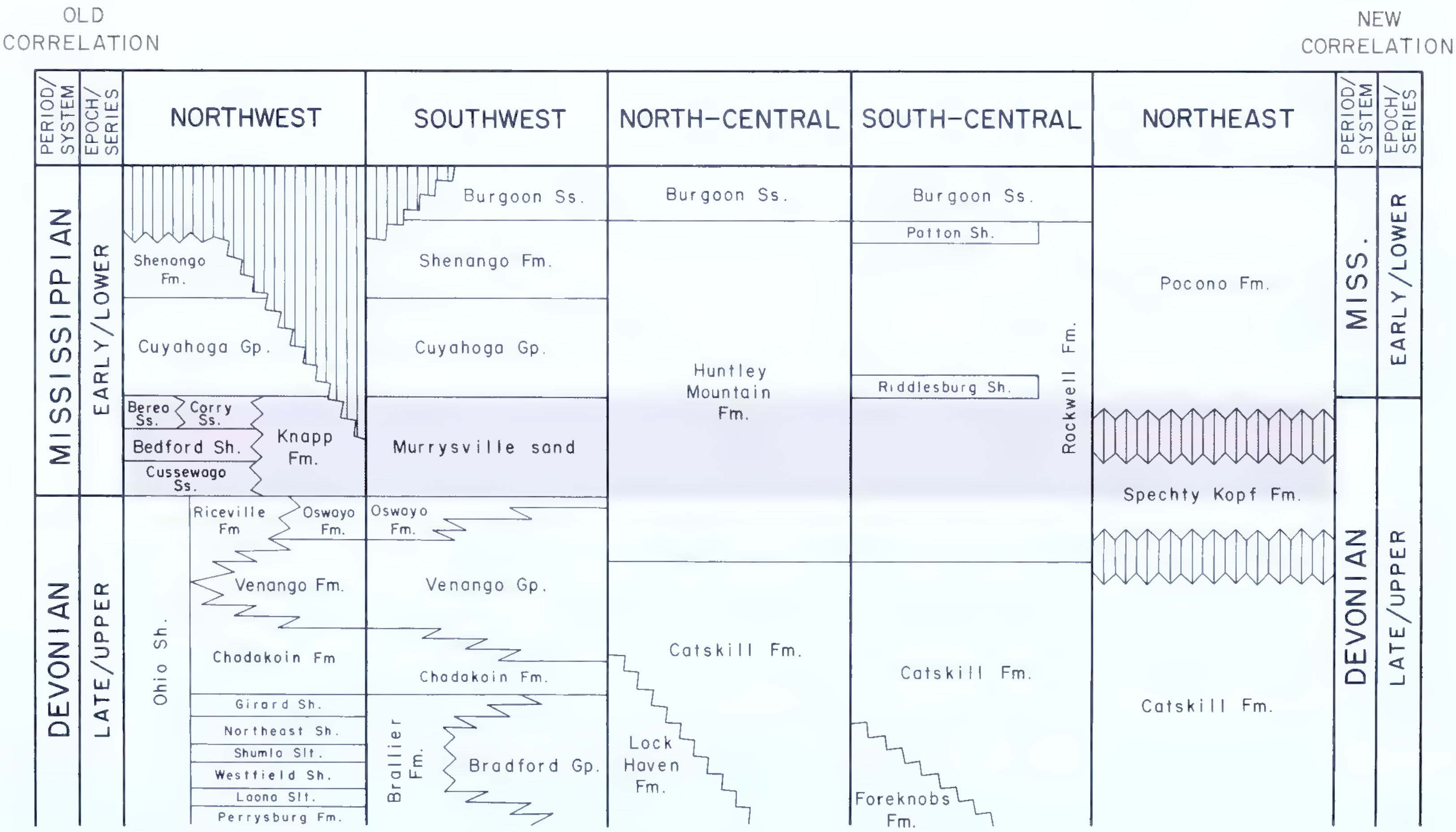

Figure 1. Correlation chart of some rock units of Late Devonian and Early Mississippian age in Pennsylvania. The highlighted area indicates the part of the stratigraphic record for which the geologic age has been changed recently.

stone" of some authors in southwestern Pennsylvania (actually the Murrysville sand) in the few outcrops that can be found along Chestnut Ridge in Fayette and Westmoreland Counties. Carter and Kammer (1990), following the practice of global biostratigraphers, unequivocally consider *Cyrtospirifer* an indicator of Devonian age. They point out that all evidence for the existence of this brachiopod genus in the Mississippian or Early Carboniferous throughout the world has been contradicted by other available data. In fact, according to one author cited in their paper, it may not even range as far as the end of the Devonian Period. In addition, Feldmann and others (1992) recorded the presence of the crustacean *Echinocaris randallii* Beecher (Figure 2C) in the Corry Sandstone at Drake Well Museum in Venango County. This fossil, a kind of bivalved shrimp, occurs elsewhere in rocks generally acknowledged to be Late Devonian in age, lending credence to the concept that the Corry is Devonian in age.

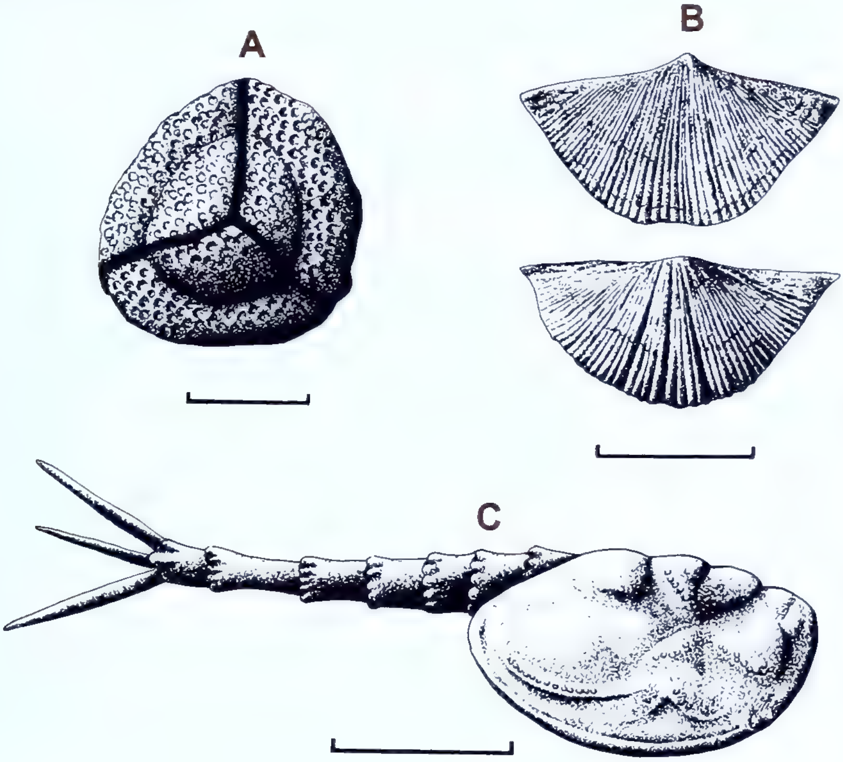

Figure 2. A, *Hymenozonotriletes lepidophytus* Kedo, a Late Devonian and Early Mississippian plant spore. Scale is 50 microns. B, *Cyrtospirifer sulcifer* (Hall), a typical species of the Devonian brachiopod genus. Top view shows pedicle valve, and bottom shows brachial valve. Scale is 25 mm. C, Partial reconstruction of *Echinocaris randallii* Beecher, a Late Devonian bivalved shrimp. Scale is 1 cm.

CHANGES ACCEPTED BY THE PENNSYLVANIA GEOLOGICAL SURVEY. The fossil evidence is indisputable. The Berea, Corry, and Knapp Formations are Late Devonian in age, and therefore the rocks beneath them, previously considered to be Mississippian, are Devonian as well. The first inarguable Mississippian-age rocks in the Commonwealth include the Cuyahoga Formation of northwestern Pennsylvania and, by correlation, the Riddlesburg Shale of south-central Pennsylvania (Figure 1).

The Pennsylvania Geological Survey recognizes and accepts the nature and importance of this change. Although we cannot revise all of our previously published reports and maps to reflect the change, certain expected revisions, such as future editions of the geologic map (Berg and others, 1980) will incorporate the new boundary. The most recent reprinting of the Pennsylvania stratigraphic correlation chart (Berg and others, 1986; reprinted in 1993) includes a written addendum concerning this boundary change. Readers should be aware of the changes when consulting the geologic literature of Pennsylvania.

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ANNOUNCEMENTS

Pennsylvania—A National Leader in the Production of Industrial Minerals

Within the past year, the U.S. Bureau of Mines held the "1992 Industrial-Mineral-Production Awards Ceremony," and Pennsylvania came away with some top honors. The Commonwealth led the nation in the production of crushed stone in 1992 and ranked among the top four states in cement and lime production. Overall, Pennsylvania ranked thirteenth in the nation for value of nonfuel minerals, accounting for 3 percent of the United States total value. This is not a new development in the long history of nonfuel mining in Pennsylvania.

Why are nonfuel minerals important to the citizens of Pennsylvania? In addition to the fact that the 1992 nonfuel-mineral production represents an estimated cumulative value of almost $865 million (the value of crushed stone, alone, represents appproximately 45 percent of this value; see Table 1), the availability of abundant industrial minerals helps

Table 1. ***Nonfuel Mineral Production in Pennsylvania***[1]
(from U.S. Bureau of Mines, 1993; quantities are in thousand short tons unless otherwise indicated)

Mineral	1990 Quantity	1990 Value (thousands)	1991 Quantity	1991 Value (thousands)	1992^{e} Quantity	1992^{e} Value (thousands)
Cement:						
Masonry	303	$22,594	^{e}253	^{e}$18,975	249	$18,675
Portland	5,621	286,185	^{e}4,881	^{e}248,931	4,675	238,425
Clays[2] (metric tons)	840,646	2,900	701,399	2,890	669,463	3,556
Gem stones	NA	5	NA	5	NA	1
Lime	1,626	92,557	1,695	95,328	1,741	97,914
Peat	18	730	10	207	W	W
Sand and gravel (construction)	20,883	97,348	^{e}18,300	^{e}87,800	18,000	88,000
Stone:						
Crushed[3]	^{e}95,800	^{e}502,700	70,334	362,306	72,700	385,700
Dimension (short tons)	^{e}43,952	^{e}9,898	38,493	10,077	41,728	10,822
Combined[4]	XX	15,125	XX	17,482	XX	19,535
Total	XX	1,030,042	XX	844,001	XX	862,628

e, estimated. NA, not available. W, withheld to avoid disclosing company proprietary data; value included with "combined value" data. XX, not applicable.

[1] Production as measured by mine shipments, sales, or marketable production (including comsumption by producers).

[2] Excludes certain clays; kind and value included with "combined value" figure.

[3] Excludes certain stones; kind and value included with "combined value" figure.

[4] Includes clays (fire [1990], kaolin), mica (scrap), sand and gravel (industrial), stone (crushed granite [1990], crushed limestone, dolomite, and quartzite [1991], crushed unidentified [1992]), tripoli, and value indicated by symbol W.

Pennsylvania's citizens maintain and expand the state's infrastructure, including highways, bridges, airports, railroad beds, and commercial and residential buildings. In addition to their use in construction, lime and limestone are used in steel making and glassmaking processes. Environmental applications of these carbonate products, such as acid neutralization, water purification, and capturing sulfur emissions, increase each year.

But what is so special about producing aggregates? Although many regions of the United States produce these commodities, it is important to realize that most construction aggregates are low-unit-price, high-volume commodities. Generally they cannot be transported more than 30 miles from their source of origin before transportation costs cause their value on a per-ton basis to double, and construction costs then become significantly higher. It may help to illustrate this point if we consider that for every citizen of Pennsylvania, approximately 45 pounds of industrial minerals are consumed daily at a cost of less than 20 cents per day! These mineral products appear to be one of the last true bargains of the century, costing less than a penny per pound. Furthermore, they are made from all-natural ingredients and can be recycled.

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Maria Crawford Receives MacArthur Fellowship

Maria Louisa (Weecha) Crawford, Professor of Science and Environmental Studies and Professor of Geology at Bryn Mawr College, has received one of 31 MacArthur Fellowships awarded in 1993. Since 1981, money from the John D. and Catherine T. MacArthur Foundation of Chicago has been distributed to exceptionally gifted individuals to spend as they choose. Dr. Crawford was awarded $320,000 to be paid over the next five years.

The money will support Dr. Crawford's site-specific research on mountain belts. This research, which has taken her to British Columbia and Alaska, may one day shed new light on the mechanisms and timing of convergent plate movement.

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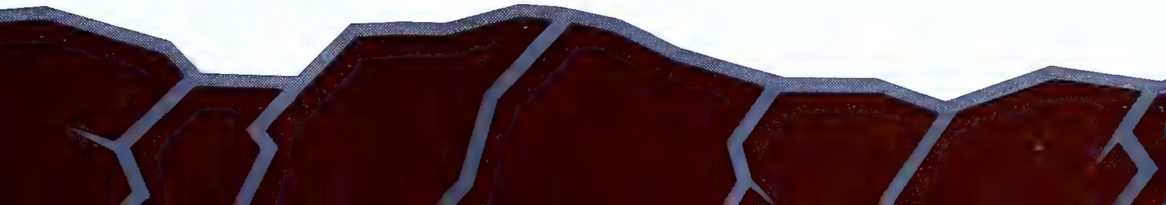

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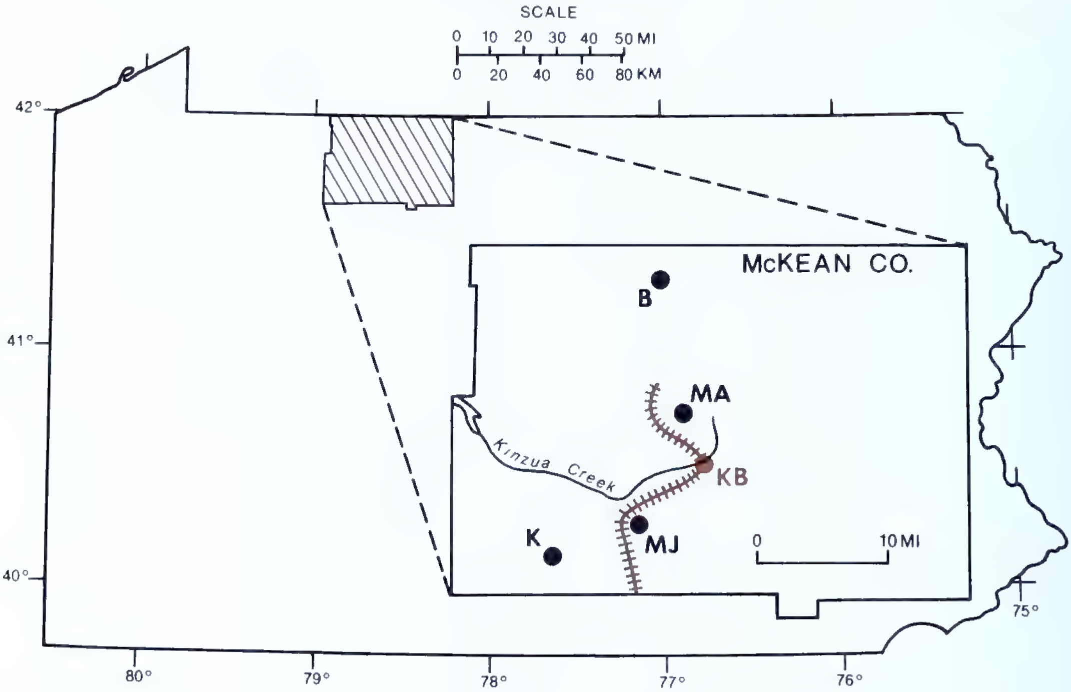
(see article on page 2)



EXPLANATION

┼┼┼┼┼┼┼┼ Trackage of the New York, Lake Erie and Western Railroad

B	Bradford	MA	Mount Alton	KB	Kinzua Bridge
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ON THE COVER

A catastrophic sinkhole, which opened on February 23, 1994, near center city Allentown, Lehigh County, caused disruption to local traffic and utility services and resulted in major structural damage to the Corporate Plaza building. The view is of the collapsed northwest corner; the building was later razed. The area is underlain by carbonate rocks of the Upper Cambrian Allentown Formation. Photograph by W. E. Kochanov.

PENNSYLVANIA GEOLOGY

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VOL. 24, NO. 4 **WINTER 1993**

STATE GEOLOGIST'S EDITORIAL

Past, Present, and Future

Geologists at the Pennsylvania Geological Survey generally spend most available time interpreting Pennsylvania's geological past to provide information of use in the present. For a brief period during the coming months, the staff of the Survey will be looking to the future, rather than the past, to examine issues and problems presently encountered for which problem-solving strategies will be developed. From this examination, we will prepare a strategic plan that should improve future services provided to you. Our efforts parallel those of the Bureaus of Forestry and State Parks, which have also recently engaged in strategic planning. The Bureau of State Parks released its plan as *Parks 2000*; the Bureau of Forestry is presently drafting its plan, entitled *Heading into Our Second Century of Stewardship.*

We are identifying major issues that we understand must be dealt with in order to more successfully accomplish our Bureau's responsibilities. After identifying issues and problems, we will conduct a series of public meetings throughout the Commonwealth to discuss these topics. If you wish to participate in these meetings, please let us know. You may also contact us directly about issues that you feel are important. Whether by attending a public meeting or by direct comment, your participation in our strategic planning will be invaluable.

One issue for which we seek your comment relates to the availability of published reports and maps of the Pennsylvania Geological Survey. Presently, completed investigations that are published by the Survey as maps or reports are transferred to the Pennsylvania Department of General Services to be sold through the State Book Store. Some maps and reports in high demand have been reprinted as stock runs low. Of late, the last copies of many high-demand reports have been sold and are now unavailable at the State Book Store. However, repository copies are available in public and academic libraries throughout Pennsylvania and neighboring states.

Available Bureau resources are presently devoted to publishing new reports; reprinting out-of-print maps and reports has low priority for allocation of resources. For out-of-print reports, does access

(continued on page 13)

Pennsylvania: Battleground of Drainage Change

by W. D. Sevon
Pennsylvania Geological Survey

INTRODUCTION. Have you ever wondered how the streams and valleys in Pennsylvania came to be in their present positions? Geologists have been pondering the subject for over 150 years and will likely do so for years to come as they are stimulated by new concepts and data. Henry Darwin Rogers (1858), director of the first Pennsylvania Geological Survey, believed the landscape and its drainage system to be a consequence of rapid uplift of the rocks from beneath ocean waters during convulsions that created the anticlines and synclines. The convulsions were caused by giant rippling in molten material deep beneath the earth's crust. He envisioned great torrents of water that rushed and swirled off the rising rocks, eroding the landscape to the form we see today. Large lakes developed in many valleys enclosed by mountain ridges. Eventually, these lakes overtopped the ridges and catastrophically cut the water gaps. Rogers' process would make a great sequence in the movie *Fantasia*.

A more realistic hypothesis based on better understanding of geological processes was offered by William Morris Davis in 1889. Davis believed that the "Permian deformation" created mountain ranges in central and eastern Pennsylvania, the highest peaks situated in Centre County and the Piedmont. He envisioned that water from the eastern side of the central Pennsylvania mountains flowed down the troughs of the synclines into a great lake covering the Anthracite region and that the lake drained through a river to the northwest. Water on the western side of the mountains flowed west across an alluvial plain. Davis was vague about the Piedmont mountains.

Davis attributed initiation of southeast-flowing drainage to development of the Gettysburg-Newark basin in southeastern Pennsylvania in the late Triassic Period. The new streams, particularly the Susquehanna River, eroded headward, and gradually all of Pennsylvania's drainage was reversed, except in the western part of the state. He believed that millions of years of erosion produced a peneplain, a relatively flat, low-relief surface, over all of Pennsylvania by the end of the Cretaceous Period, about 70 million years ago. Davis considered the landscape we see today to be the result of erosion of the peneplain, and the even-crested ridges of central Pennsylvania to be remains of the former peneplain.

There has been little challenge to the basic concept of Davis, except for questioning the reality of the peneplain and suggestions of alternate ways to form water gaps. However, the development and widespread acceptance of the concept of plate tectonics since 1970 has given us a new understanding of what happened during the "Permian deformation," thus making it desirable to create a new model of drainage evolution for Pennsylvania. A probable model is presented here.

IN THE BEGINNING: THE ALLEGHANIAN OROGENY. The evolution of Pennsylvania's present drainage system began with the Alleghanian orogeny. Prior to that orogeny, Pennsylvania was part of the Appalachian basin, an elongate feature occupied by an inland sea in which sediment had accumulated for almost 200 million years. The sea ceased to exist when the continents of Africa and North America collided between 260 and 240 million years ago, during the Permian Period.

Compression from the collision created faults, called décollement faults, that paralleled bedding of the sedimentary rocks and extended at great depths beneath the surface across much of Pennsylvania (Figure 1). Splays (faults that angle toward the surface from the décollements) displaced rock upward, producing anticlines throughout the central part of Pennsylvania. In eastern Pennsylvania, large sheets of rock were thrust along faults and stacked to a

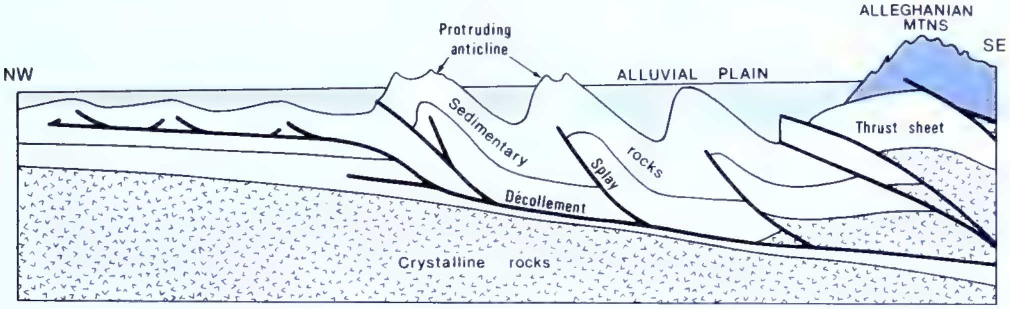

Figure 1. Cross section showing folds, faults, mountains, and alluvial plain resulting from the Alleghanian orogeny.

depth of 5 or 6 miles (Beaumont and others, 1987). One of these sheets was thrust out over much of the Anthracite region (Levine, 1986). The stacked thrust sheets created a mountain range having 2 to 3 miles of relief and a width of 150 miles or more (Slingerland and Furlong, 1989). These mountains, the Alleghanian Mountains, were probably similar in size to the present Andes Mountains in South America.

Erosion occurred throughout this whole process. Streams flowing to the west and northwest carried away the sediment eroded from the Alleghanian Mountains and deposited it on an alluvial plain that extended from the base of the mountains to somewhere west of Pennsylvania (Figure 2). The crests of some anticlines, particularly those in Centre County, almost certainly rose above the level of the alluvial plain, but most of the anticlines, especially those closest to the mountains, were buried by alluvial sediments. The amount of sediment carried to the alluvial plain decreased as erosion lowered the mountains to hills. By the time deposition on this plain ceased, the westward-thinning wedge of sediment may have approached 2.7 miles in thickness in eastern Pennsylvania, 2.4 miles at the Al-

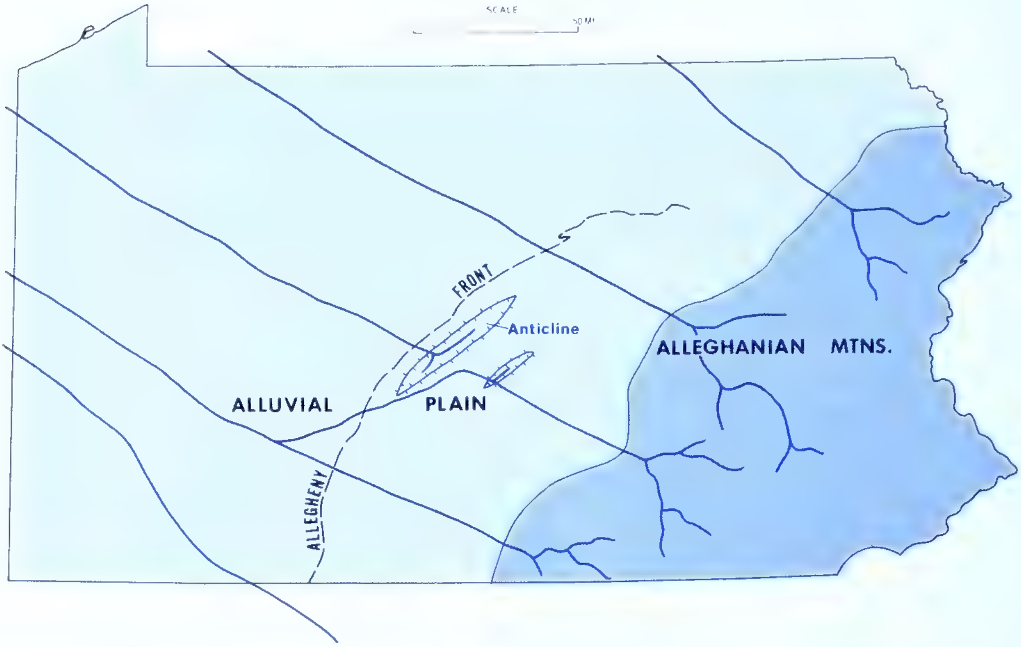

Figure 2. Paleogeographic map of Pennsylvania in the early Triassic Period showing mountains, alluvial plain, streams, and protruding anticlines. Streams originated in the Alleghanian Mountains and flowed northwest.

legheny Front, and 1.5 miles at the Ohio-Pennsylvania line (Zhang and Davis, 1993).

THE NEXT STEP: RIFTING OF THE CONTINENTS. This simple pattern of erosion in the east and deposition to the west would have continued indefinitely had it not been for plate tectonics. The forces that drove the continents together, convection currents deep within the earth, reversed their flow directions and forced the continents apart. Africa and North America began to separate about 210 million years ago, in the late Triassic Period. The tension created by the process of separation caused development along the eastern margin of North America of numerous small, elongate basins, such as the Mesozoic-age Gettysburg-Hammer Creek-Newark basin in southeastern Pennsylvania. These basins were filled with sediment eroded from adjacent areas. Most of the sediment came from highlands to the east, but in Pennsylvania some was brought in by new streams, the Susquehanna and Schuylkill Rivers and possibly the Delaware River, that entered the basin from the northwest (Figure 3).

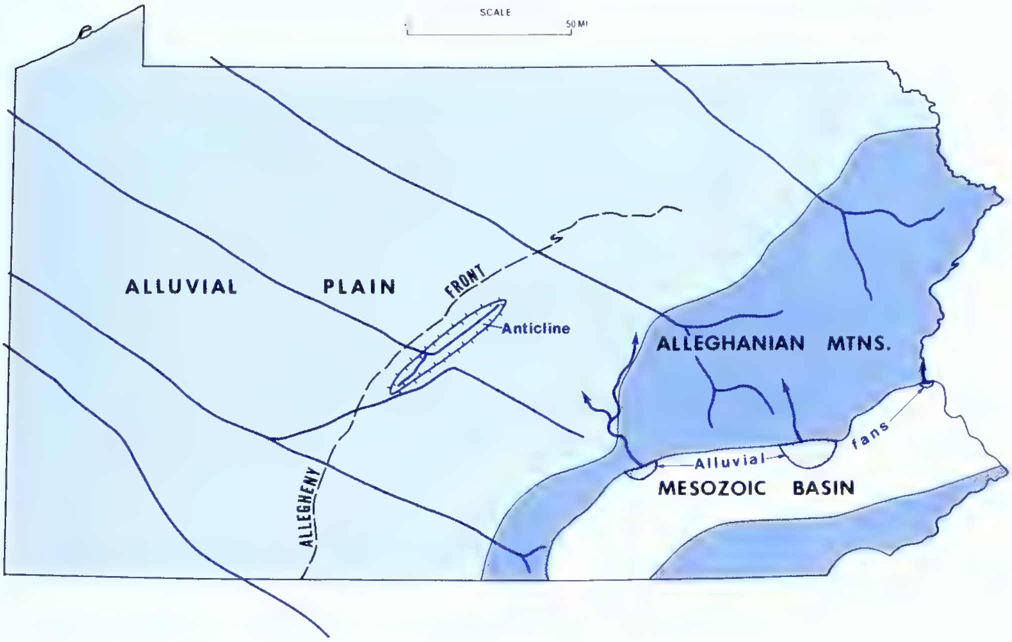

Figure 3. Paleogeographic map of Pennsylvania in the early Jurassic Period showing mountains, alluvial plain, Mesozoic basin, and northwest-flowing and southeast-flowing streams. Arrows indicate direction of headward erosion.

Once established, the southeast-flowing streams began to erode headward. These new streams had steep gradients and eroded aggressively. The Susquehanna River probably eroded headward following the boundary between the rocks of the Alleghanian Mountains and the poorly consolidated sediments of the alluvial plain. Erosion along this boundary allowed it to progress rapidly and become the dominant stream in Pennsylvania (Figure 4). The Schuylkill and Delaware Rivers eroded entirely into rock and did not progress as rapidly. As the Susquehanna River lengthened its course, two important things happened: (1) it developed a larger drainage basin and, with more water available, it eroded more rapidly; and (2) it beheaded westward-flowing streams that carried water and sediment to the alluvial plain. Beheading of these westward-flowing streams deprived them of both water and sediment, and they changed from depositional streams to erosional streams. However, these beheaded streams had low gradients and relatively little water, so they were not very effective at erosion.

MOVING RIGHT ALONG: THE PROGRESSION OF EROSION. When the Susquehanna River and its tributary the Juniata River eroded through the westward-sloping alluvium, they encountered

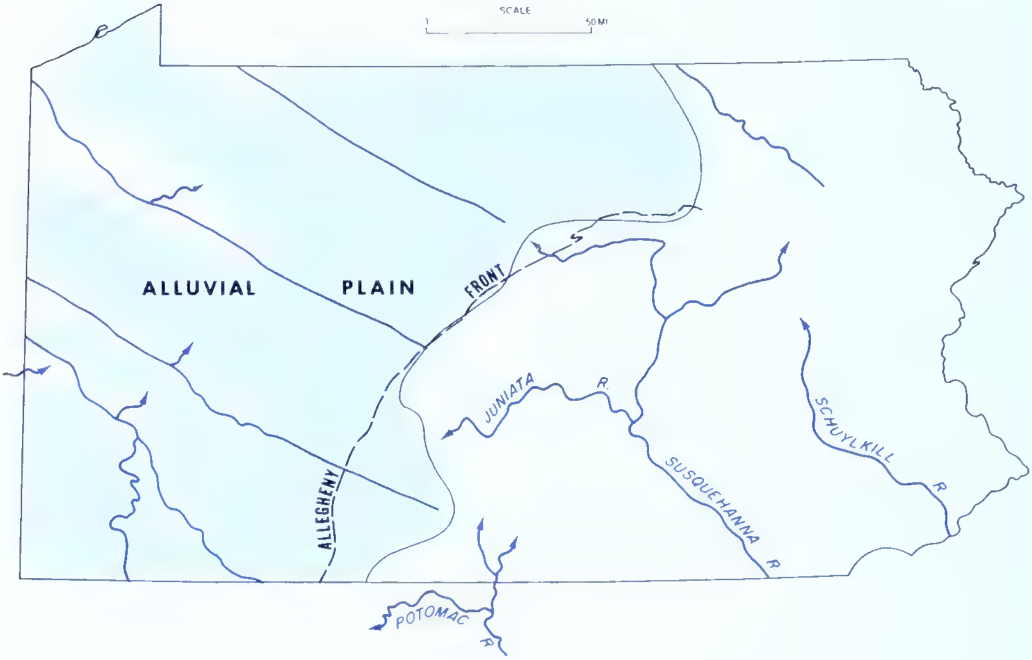

Figure 4. Paleogeographic map of Pennsylvania in the Cretaceous Period showing remnant alluvial plain and positions of headward-eroding streams.

the underlying folded rocks. In many places, the streams were superimposed across structural trends, whereas in other places stream positions were altered by structure. Tributaries to the main streams adjusted to structural trends as they eroded headward. When the Susquehanna River eroded headward into the Appalachian Plateau northwest of Lock Haven, its course was controlled by structure. As a result, the principal elongation parallels fold trends, whereas tributaries cross fold trends (Figure 5).

In western and northwestern Pennsylvania, a much different process operated. There, the pre-Permian rocks dip gently to the south and southwest. When northwest-trending streams eroded through the alluvium to the underlying rocks, their tributaries began to erode preferentially updip (north and northeast) wherever a resistant rock, such as sandstone of the Pottsville Formation, was encountered (Lattman, 1954). These tributaries became elongated updip and eventually beheaded another northwest-flowing stream. The result was an integration of several different streams to form the present Allegheny River system (Figure 5), a process that may have been enhanced by glaciation.

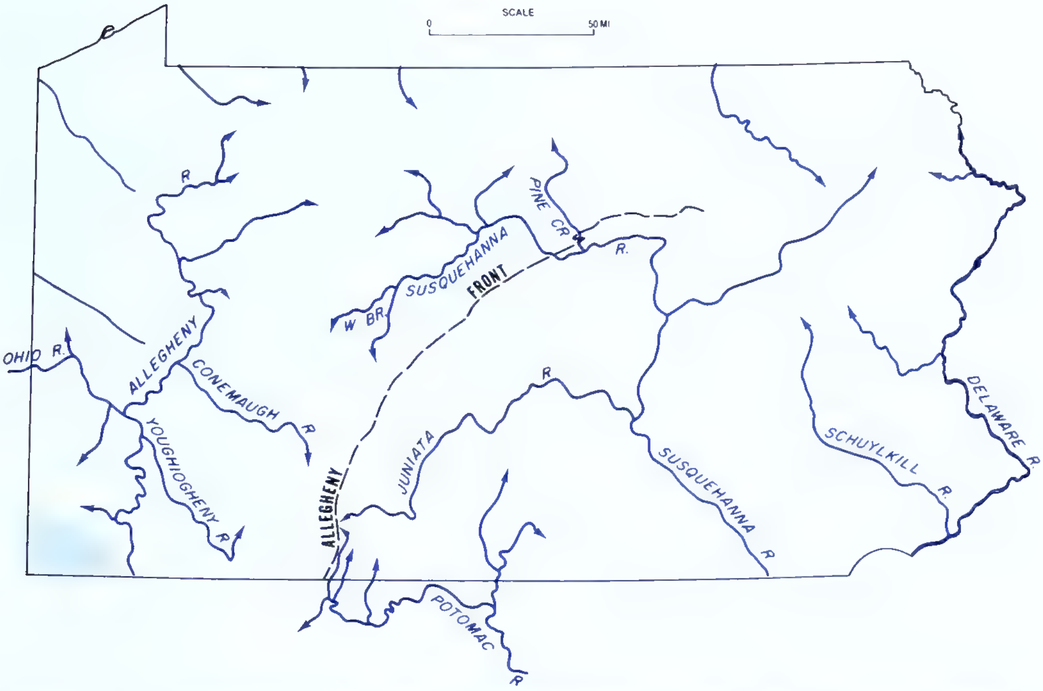

Figure 5. Paleogeographic map of Pennsylvania in the early Tertiary Period showing positions of headward-eroding streams.

Southwestern Pennsylvania is the only area in the Commonwealth where drainage may be at least partly descended from the original west-flowing streams. The Youghiogheny and Conemaugh Rivers appear to be streams that cut through the former alluvial plain and became superimposed across fold trends (Figure 5). Tributaries to these streams are well adjusted to structure.

WHAT NEXT: THE FUTURE. What is the future of drainage evolution in Pennsylvania? The present drainage pattern will be around for a long time. Given enough time, it is probable that the Susquehanna River drainage will eventually include all of Pennsylvania north and west of the Anthracite region. Streams will continue to adjust to structure. If erosion in western Pennsylvania ever progresses to the point that rocks of pre-Silurian age are encountered, there will be a gradual reorientation of the streams as they adjust to the east-southeast regional dip of those rocks. How long will all of this take? Calculated rates of present erosion in the Appalachians are variable, but a rate of less than 100 feet per million years is reasonable. Unless something happens that dramatically increases the rate of erosion, such as climate change, the drainage pattern in Pennsylvania will not change significantly for many millions of years.

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Earthquakes 1993

by Richard N. Benson
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RECENT EARTHQUAKES IN THE MID-ATLANTIC REGION. On February 26, 1993, a 2.7-magnitude (Richter scale) earthquake was felt near Cherry Hill, N. J., and was the first of 24 small quakes within the mid-Atlantic region (Figure 1) recorded through May 20 by the three seismographs in northern New Castle County, Del., operated by the Delaware Geological Survey (DGS).

Later, areas nearby in two other states experienced multiple events. From March 10 to April 8, nine earthquakes were recorded in the Columbia, Md., area with magnitudes ranging from 1.0 to 2.7. These prompted many telephone calls to Maryland officials. As the DGS has the seismograph network closest to the Columbia area, we were asked by our counterparts at the Maryland Geological Survey to provide data on the events. Subsequently, the Baltimore and Washington news media contacted DGS staff for information and interviews. More recently, the Reading, Pa., area was the location of 10 or 11 events having magnitudes of less than 1.5 to 2.8, recorded from May 10 to May 20, 1993 (Figure 1).[1]

Single earthquakes having magnitudes of less than 2.0 were detected near Bel Air, Md., on March 21 and the next day near Lancaster, Pa. On May 15, a coastal New Jersey event (just off the map shown in Figure 1) was estimated to be of 2.6 magnitude.

A quake of magnitude 2 is about the lowest limit normally felt by humans. At magnitudes of greater than 4 to 5, sleepers may be awakened and small objects are upset, and at greater than 5 to 6, some minor damage may occur. However, in the eastern United States, smaller magnitudes produce larger intensities than this, and slight damage may occur at magnitudes around 4. The Richter scale is

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[1] EDITORS' NOTE: While this issue of the magazine was in press, additional earthquakes occurred on January 15, 16, and 17, 1994, in the Reading area. The maximum magnitude was 4.6, the highest yet recorded in Pennsylvania. A follow-up article on these earthquakes will be printed in a later issue.

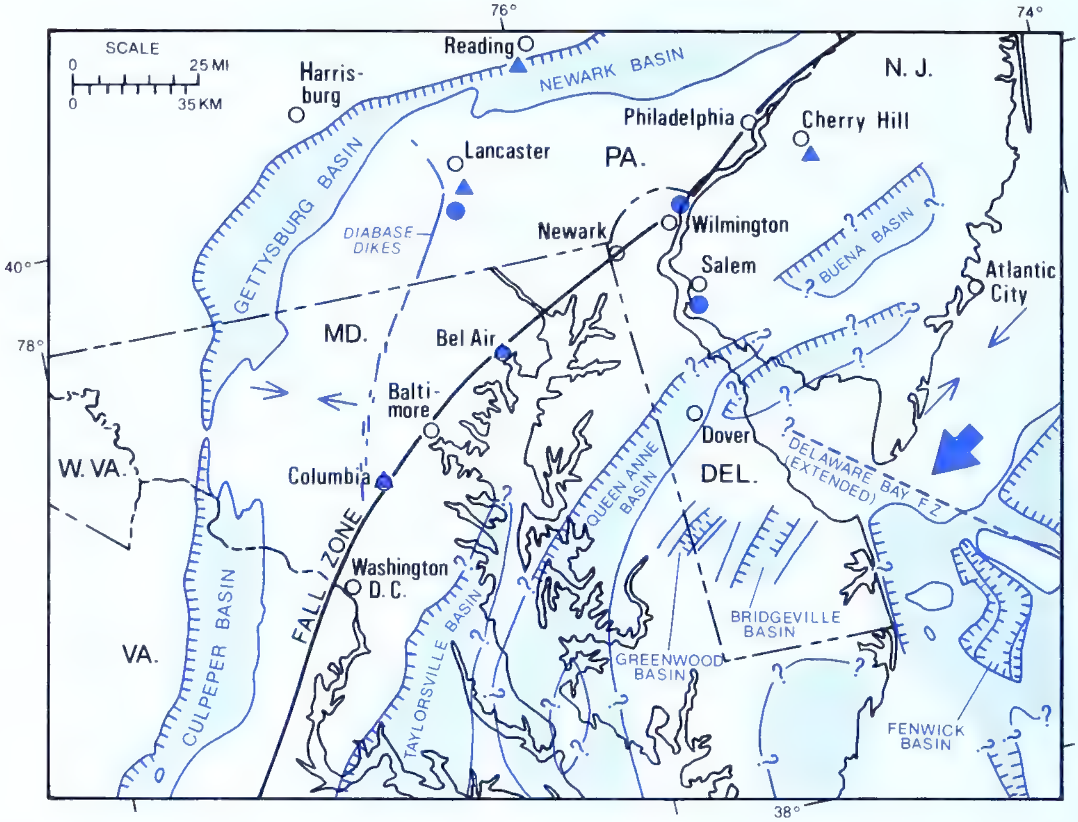

Figure 1. Locations of recent earthquakes in the mid-Atlantic region. Solid triangles mark areas of 1993 events; solid circles represent some previous events, including the 1984 earthquakes near Lancaster. The large single arrow indicates the direction of absolute motion of the mid-plate of the North American plate (after Zoback and Zoback, 1991). The large inward-pointing arrows show the orientation of the average compressive tectonic stress field of the region; small inward-pointing arrows indicate the local variation of NW-SE compression (after Zoback and Zoback, 1989). Exposed (northwest of the Fall Zone) and inferred (buried) Mesozoic rift basins are after Benson (1992); fault zones are indicated by hachures. Diabase dikes are after Emery T. Cleaves and James P. Reger, Maryland Geological Survey (written communication, 1993). The trend of the extended Delaware Bay fracture zone (F.Z.) is after Klitgord and Schouten (1986).

logarithmic; a recording of 6, for example, indicates ground motion 10 times as large as a recording of 5.

FRACTURES, STRESSES, AND BODY WAVES. Earthquakes in the northeastern United States generally occur in the upper half of the earth's crust. The focal depths determined from a sampling of earthquake records for this region tend to cluster in a zone between 5 and 15 km beneath the earth's surface; the deepest generally are at 20 km, and the shallowest are at about 1 km.

An earthquake occurs when blocks on either side of a fracture in the earth's crust (termed a fault) suddenly break or "snap" to new positions. The earth's crust is constantly under stress as a result of forces operating on the earth's outer brittle layer, the lithosphere, which is subdivided into several tectonic plates. Friction along active faults keeps the blocks of crust from moving past one another continuously. Under constantly applied stress, the strains in the blocks build to a point until rupture occurs, releasing energy in the form of body waves that travel in all directions through the earth from the focal point of the earthquake. Body waves that reach the earth's surface generate surface waves, which usually have the strongest vibrations and probably cause most of the damage done by earthquakes.

There are two types of body waves: compressional, called primary or P waves, and shear, called secondary or S waves. As a P wave travels through the earth, it pushes particles of material ahead of it closer together, but behind it the particles rebound to positions farther apart from one another than when the material was at rest. S waves, on the other hand, displace material in directions at right angles to their paths of travel.

Because P waves travel through the earth at higher velocities than S waves, they are the first to be detected by seismographs. With knowledge of the velocity of P and S waves, the difference in arrival times between the P and S waves on a seismogram can be used to measure the distance between the seismograph and the epicenter of the earthquake, which is the location on the earth's surface directly above the focal point. The seismogram shown in Figure 2 for the May 18, 1993, Reading, Pa., earthquake of magnitude slightly greater than 2 indicates a 9.1-second difference in the arrival times of the P and S waves. This calculates to a distance of about 70 km between the seismograph in northern Delaware and the epicenter, which could be anywhere on a circle of that radius centered on the seismograph location. In order to locate the epicenter, there must be at least two more circles centered on other seismograph locations that intersect the first circle to define a single point. For the example shown, seismologists at the Lamont-

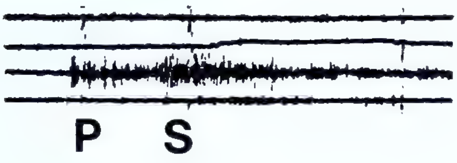

Figure 2. DGS seismogram of the May 18, 1993, earthquake near Reading. The estimated magnitude is slightly greater than 2. The difference between the arrival times of the P and S waves is 9.1 seconds.

Doherty Earth Observatory of Columbia University determined the location of the epicenter near Reading.

COMPRESSIVE STRESS FIELD AND ZONES OF WEAKNESS. Earthquake activity in the northeastern United States is quite low compared to that of the boundaries of the earth's tectonic plates, which are located several thousand kilometers from this region. In the broad intraplate region of the North American plate, researchers, using a variety of methods, have measured the tectonic stress field and have concluded that the central and eastern United States, most of Canada, and possibly much of the western North Atlantic basin to within about 250 km of the Mid-Atlantic Ridge is under a uniform compressive stress field. Faulting (earthquakes) occurring under these conditions is dominated by reverse faults (one block of the earth's crust moves up and over another block along an inclined fault plane) and strike-slip faults (blocks move past one another along a near-vertical fault plane). The compression has an average ENE-WSW orientation that is also remarkably near parallel with the WSW direction of absolute plate motion of this large midplate province (Figure 1). The uniformity of the stress field suggests that it arises from forces that either drive (ridge push) or resist (basal drag) plate motions. A local variation of the uniform stress pattern is observed in Maryland and eastern Virginia, where reverse faults of Miocene and younger age indicate apparent northwest-southeast compression (Figure 1). Analysis of the Wilmington earthquake of February 28, 1973, also suggests northwest-southeast compression.

In California, faults responsible for earthquakes are well known, but for the northeastern United States, earthquake faults are difficult to identify. Faults that have been mapped at the earth's surface were zones of weakness under preexisting stress regimes in the geologic past, and researchers commonly explain northeastern United States earthquakes as the result of these ancient zones of weakness being reactivated if favorably oriented in the present-day stress field. Leading candidates are faults inherited from the extensional stress fields that characterized continental rifting and eventual breakup of the supercontinent of Pangea during the early Mesozoic Era, followed by the separation of Africa and Europe from North America. These faults, in turn, may have been inherited from zones of weakness created during the compressional tectonics that characterized the Appalachian mountain-building episodes of the Paleozoic Era.

Possible zones of weakness that may be responding to the current ENE-WSW compressive stress field or the local NW-SE compression in the mid-Atlantic region include Mesozoic rift basin border faults; faults associated with a series of Mesozoic diabase dikes extending from the area of Columbia, Md., to Lancaster, Pa.; the Fall Zone, which marks the boundary between the Piedmont and Atlantic Coastal Plain provinces; and, possibly, the Delaware Bay fracture zone of the western North Atlantic basin that if extended into continental crust would trend northwestward beneath Delaware Bay.

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Past, Present, and Future *(continued from page 1)*

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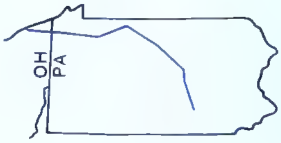
Donald M. Hoskins

Donald M. Hoskins
State Geologist

NEW PUBLICATION

Stratigraphic Framework of Cambrian and Ordovician Rocks



Students of Appalachian basin stratigraphy and structural geology will be interested in a new publication issued by the U.S. Geological Survey (USGS). The report is Miscellaneous Investigations Series Map I–2200, a cross section of the Lower Paleozoic stratigraphic interval between the Lower Silurian and the Precambrian compiled from drill-hole data by USGS geologist Robert T. Ryder. The cross section has been drawn from northeastern Ohio near Cleveland, across northern Pennsylvania to Potter County, and down across central Pennsylvania, where it terminates northwest of Harrisburg. Six colors and two patterns representing the dominant lithologies aid in distinguishing formations; additional symbols identify significant lithologic constituents such as anhydrite, oolites, chert, and red beds, and stratigraphic markers such as metabentonite (altered volcanic ash).

This cross section and others still in press provide important stratigraphic and lithologic information for the Lower Paleozoic interval. The cross section also delineates the top of the Precambrian basement rocks beneath the Appalachian basin. The top of Appalachian basement structure is inadequately known at present because only a few holes have penetrated the Paleozoic sedimentary cover, magnetic and gravity data have not been calibrated satisfactorily to known basement rock types and structures, and very little seismic information exists outside proprietary industry files. The inadequacy of the available information allows a great deal of speculation about the configuration of the basement in Pennsylvania. For example, published and open-file reports written about basement structure in western Pennsylvania since 1970 suggest the existence of the Rome trough, a large basement graben feature known to occur in Kentucky and West Virginia. Like many of these reports, Ryder's cross section uses a combination of stratigraphic and structural variations in the Paleozoic sedimentary rock cover, and published seismic survey and gravity data, to infer the existence of the trough and other basement faults and fault blocks. Ryder's interpretation of these data differs enough from previous interpretations, however, to provide a provocative twist to the entire concept of the Rome trough in Pennsylvania. This cross section should help stimulate some welcome new debate in the coming years.

Map I–2200 is entitled **Stratigraphic Framework of Cambrian and Ordovician Rocks in the Central Appalachian Basin from Lake County, Ohio, to Juniata County, Pennsylvania**. It is available from the U.S. Geological Survey, Map Distribution, Federal Center, P. O. Box 25286, Denver, CO 80225, for $3.25 plus $1.00 for handling. Payment must accompany the order. Please make checks payable to *Department of the Interior—USGS*.

ANNOUNCEMENTS

Last Chance for 15-Minute Maps of Pennsylvania!

The U.S. Geological Survey (USGS) is officially abandoning the 15-minute (1:62,500-scale) topographic map series. The USGS has not reprinted or revised any of the 15-minute maps for many years. The supply of maps in the USGS Map Distribution Center has dwindled until only 26 of the nearly 260 15-minute quadrangles that include parts of Pennsylvania remain to be sold. Until June 1, 1994, you may purchase copies of these maps in lots of 100 each, at 50 cents per map (reduced from the previous price of $2.50 per copy). The minimum order is thus $50.00. After June 1, 1994, only microfilm or reproducible separates will be available.

The 15-minute series was replaced by the 7.5-minute series (nearly 880 individual quadrangles in Pennsylvania), which is maintained through a federal/state cooperative program of continual revision and reprinting. Additionally, the USGS and the Commonwealth cooperate in maintaining a county topographic map series at the scale of 1:50,000, which is close to the now-abandoned 1:62,500 scale. The modern 1:50,000-scale county map series is useful for those who need the accuracy of the 7.5-minute maps but require a smaller map size.

If you like old maps or wish to have 15-minute maps for teaching or other purposes, now is your last opportunity to purchase original paper copies of these maps. The locations of the available 15-minute maps are shown on the map on the back cover of this issue, and the order number for each quadrangle is listed in the map explanation.

The maps may be purchased from the U.S. Geological Survey, Map Distribution, Federal Center, P. O. Box 25286, Denver, CO 80225. Please make checks payable to *Department of the Interior—USGS.*

Pennsylvania Native Receives Hydrogeology Division Award of Distinguished Service

At the October 1993 meeting of the Geological Society of America (GSA), Dr. Paul Seaber, born in Lititz, Pa., and a 1954 graduate of Franklin and Marshall College in Lancaster, Pa., received the GSA Hydrogeology Division Award of Distinguished Service. Dr. Seaber served with the U.S. Geological Survey, Water Resources Division, in the Pennsylvania District, where he conducted an appraisal study of groundwater resources of the Susquehanna River basin that produced a pioneering analysis of the role of groundwater economics in river-basin planning.

Dr. Seaber also worked in Pakistan, India, Senegal, Kuwait, Oman, Alaska, and Florida as a member of the USGS, later joining the Illinois Geological Survey. He is now at the Desert Research Institute in Nevada. Dr. Seaber's long public service and pioneering investigations, as well as his service to local and national scientific societies in fostering understanding of groundwater, led to his award.

Pennsylvania can be justly proud of another native son.

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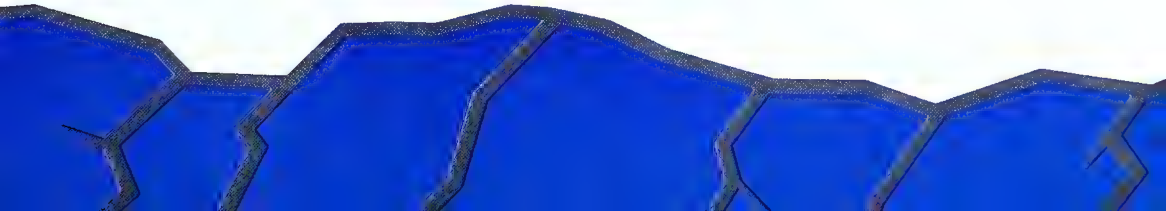
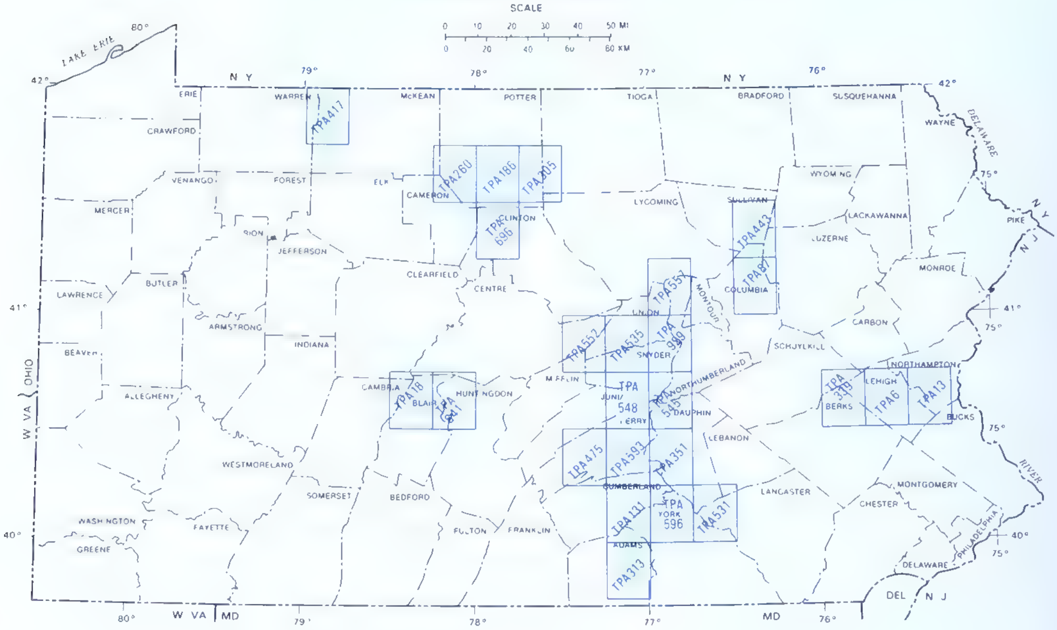


AVAILABLE 15-MINUTE-QUADRANGLE MAPS

(see article on page 15)



EXPLANATION

MAP NAME	ORDER NUMBER	MAP NAME	ORDER NUMBER	MAP NAME	ORDER NUMBER
Alburtis	TPA6	Hamburg	TPA339	Millheim	TPA552
Allentown	TPA13	Harrisburg	TPA351	Milton	TPA557
Altoona	TPA18	Kinzua	TPA417	New Bloomfield	TPA593
Bloomsburg	TPA87	Laporte	TPA443	New Cumberland	TPA596
Carlisle	TPA131	Loysville	TPA475	Renovo West	TPA696
Conrad	TPA186	Middletown	TPA531	Renovo West	TPA694
Emporium	TPA260	Mifflinburg	TPA535	(shaded relief)	
Galeton	TPA305	Millersburg	TPA545	Sunbury	TPA929
Gettysburg	TPA313	Millerstown	TPA548	Tyrone	TPA841

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ON THE COVER

Rutiodon, a Late Triassic phytosaur (a primitive crocodile-like reptile), hisses at a herd of passing fabrosaurs (primitive ornithischian dinosaurs). See article on page 3. Illustration by Douglas Henderson; used by permission.

PENNSYLVANIA GEOLOGY

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GUEST EDITORIAL

Geologists from the New School: Students, Science, and the Environment in the '90's

The 1990's is a time of increased environmental awareness when students and professionals focus on "saving the earth." Environmentalism has been around for quite a few years; however, the environmental movement of the '90's seems to have given a new sense of responsibility to the field of science. Environmental scientists today realize that a multidisciplinary approach is necessary to understand and stabilize the effects of human activities on the biosphere; it is not enough merely to save the whales, beaches, or forests to save the earth.

It is within this school of thought that young environmental scientists entering college begin to explore the earth sciences. Here the ambitious pursuers of "earth saving" stumble upon the curious subject of geology. Although geology is defined as the study of the earth, most people first think of it only as the study of rocks. Yet, many students who have environmental interests choose geology as their field of study because it offers a greater challenge and broader perspective than other earth sciences. Environmental geology, hydrogeology, and geochemistry are demanding subdisciplines that focus on environmental issues.

Environmental geology is the study of the application of geologic principles to the interaction between the human race and the physical environment. This theme includes a diverse range of subjects dealing primarily with the interrelationships among geologic processes, earth materials, and humanity. Common topics include waste disposal, geologic hazards, mining and reclamation, and urban geology.

Hydrogeology is another subdiscipline in geology that has an environmental focus. The study of the hydrologic cycle and water chemistry enables the evaluation of water quantity and quality. Understanding groundwater dynamics is important in waste disposal and aquifer contamination issues.

Geochemistry provides some understanding of natural chemical systems. The study of the abundance and distribution of the elements in earth systems furnishes a baseline for an examination of changes in earth chemistry through time. Although it is more abstract than other topics in geology, geochemistry supplies data for the analysis of fundamental environmental issues such as the effects of pollution on the chemical systems of the atmosphere and the oceans.

Geologists play an important role in the multidisciplinary approach to problem solving. Geology provides a unique point of view to the scientific understanding of environmental problems. Most environmental science subdisciplines focus on the present; however, geology includes the study of the earth's 4.6 billion years of history. Not only is the present the key to the past, but the past gives insight to the present. Many earth events and processes are cyclic; thus, understanding the processes of the past aids in the interpretation of today's problems. For example, warming of the atmosphere may be a part of a thermal cycle of global warming and cooling and not due to the greenhouse effect. This perspective gives the geologist additional insight to problems that might be overlooked by scientists in other disciplines.

A new generation of scientists is emerging from colleges and universities around the country. Products of the environmental movement of the 1990's, these scholars bring to the scientific community a fresh sense of responsibility and purpose. These new environmental scientists are armed not only with an education and the voice of a generation, but a few also carry a rock hammer and a Brunton.

—Thomas R. Wyland, Jr.

STATE GEOLOGIST'S NOTE: *Tom Wyland is an undergraduate student at The Pennsylvania State University and has been employed by the Pennsylvania Geological Survey as a student intern. While at the Survey over the 1993 winter break, Tom submitted the above commentary, which reflects at least one student's perspective of the changing nature of geologic education and its applications to solving present-day problems. I found his comments refreshing, indicative of the caliber of future professional geologists and worthy of publication for your consideration. I invite other authors to submit commentary on current issues of concern in geology for publication as a guest editorial.*

Donald M. Hoskins

Donald M. Hoskins
State Geologist

Finding Phytosaurs in Pennsylvania: the Story of Stahle, Sinclair, and Zions View

by William E. Kochanov, Pennsylvania Geological Survey, and
Robert M. Sullivan, The State Museum of Pennsylvania

Serendipity is a normal part of fossil collecting, as any seasoned paleontologist will attest. Recently, during paleontological reconnaissance of Upper Triassic rock exposures in southeastern Pennsylvania, at a small roadside exposure of the Brunswick Formation (Figure 1), we found a strangely shaped shiny black "pebble" about three fourths of an inch long. Examination of the specimen under magnification quickly established that it was a tooth (Figure 2) because it was pointed at one end, blunt at the other, and had minute striations along the entire length of the visible crown edge. Upper Triassic strata commonly contain isolated teeth of extinct vertebrates. From what sort of animal did this tooth come?

During the ride home, we talked of the possibility that the specimen was a dinosaur tooth. To date, no fossil bones of dinosaurs have been discovered in Pennsylvania. However, teeth identified as *"Thecodontosaurus"* that were collected in Pennsylvania (Huene, 1921) have recently been assigned to a new dinosaur genus (Hunt and Lucas, 1994). Back at the laboratory in the Paleontology and Geology Section of The State Museum of Pennsylvania, it was determined that the newly col-

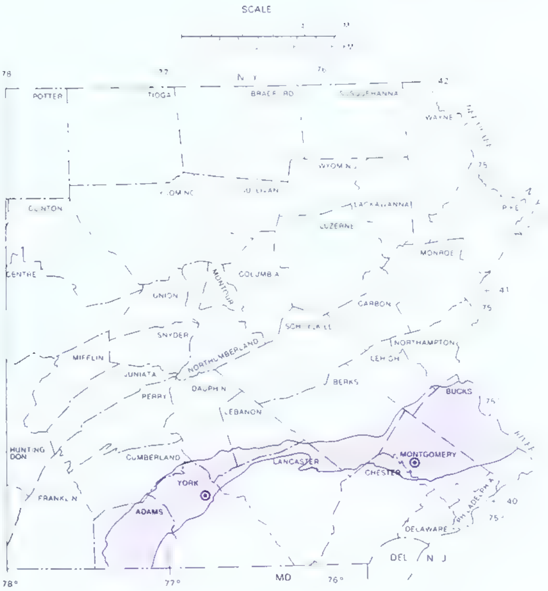
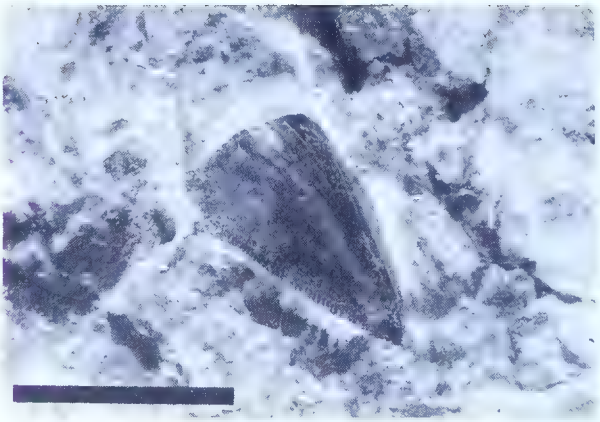


Figure 1. Generalized map showing the extent of lower Mesozoic bedrock (which includes the Brunswick Formation) in southeastern Pennsylvania and the phytosaur sites in Collegeville, Montgomery County, and Zions View, York County.

Figure 2. Phytosaur tooth (SMP VP–156) from the Upper Triassic Brunswick Formation, Montgomery County, Pa. Based on the fact that only one species of phytosaur is currently recognized in eastern North America, the tooth probably belongs to *Rutiodon carolinensis*. The scale is 1 cm. Photograph by Claire Messimer.



lected tooth was not from a dinosaur; rather, it belonged to a member of an extinct group of reptiles commonly known as phytosaurs.

THE PHYTOSAURIA. Phytosaurs are a group of archaic thecodont reptiles that looked like modern crocodiles. They were semiaquatic and grew to lengths of up to 15 feet. Like modern crocodiles, their mouths contained numerous sharply pointed teeth, which indicates that these animals were carnivorous. Unlike crocodiles, which have the external nares (nostrils) at the tip of the rostrum (nose), their external nares were located on the top of the skull, just in front of and between the eyes. The phytosaur skeleton was very primitive and superficially resembled that of a crocodile, with the back and tail covered by numerous bony plates called osteoderms. Phytosaurs preceded true crocodilians but were not ancestral to them. However, because they share many primitive features and had a similar overall body form, phytosaurs may be considered the ecological equivalent of crocodiles.

Four genera of North American phytosaurs are currently recognized: *Angistrorhinus, Paleorhinus, Pseudopalatus,* and *Rutiodon*. Emmons (1856) was the first to name a phytosaur from eastern North America and coined the name *Rutiodon carolinensis* for teeth from the Triassic of North Carolina. This species is the only known phytosaur from the East Coast (Ballew, 1989).

STAHLE, SINCLAIR, AND ZIONS VIEW: EARLY DISCOVERIES IN PENNSYLVANIA. Phytosaur remains (teeth and bones) were first reported from the Upper Triassic of Pennsylvania by Lea (1856). Additional material was cited by Rogers (1858) from the Phoenixville Tunnel (Montgomery County). But one of the earliest, and most significant, discoveries of phytosaur material in Pennsylvania occurred more than 80 years ago, in the York County hamlet of Zions View.

In 1909, Dr. Robert Spangler Stahle (Figure 3), a York medical doctor, discovered a concentration of fossilized bone in Triassic rocks (New Oxford Formation) that crop out in the streambed of Little Conewago Creek. The discovery, and the eventual disposition of these Zions View vertebrate fossils, are revealed in a series of letters written from 1910 to 1912 between Stahle and Professor William J. Sinclair of Princeton University (Figure 4). Although we have only copies of Sinclair's letters, we can piece together an interesting sequence of events ranging from the thrill of discovery to devastating disappointment.

Late in 1909, Stahle apparently wrote a letter of inquiry to the University of Pennsylvania announcing his discovery of fossilized bones in York County. This letter was forwarded to Sinclair at Princeton, who expressed deep interest in examining the specimens. Believing that the material was that of a dinosaur, Sinclair offered to purchase it from Stahle for the outrageous sum (compared to today's standards) of $75, with a one-time bonus of $50 for the rest of the skeleton if

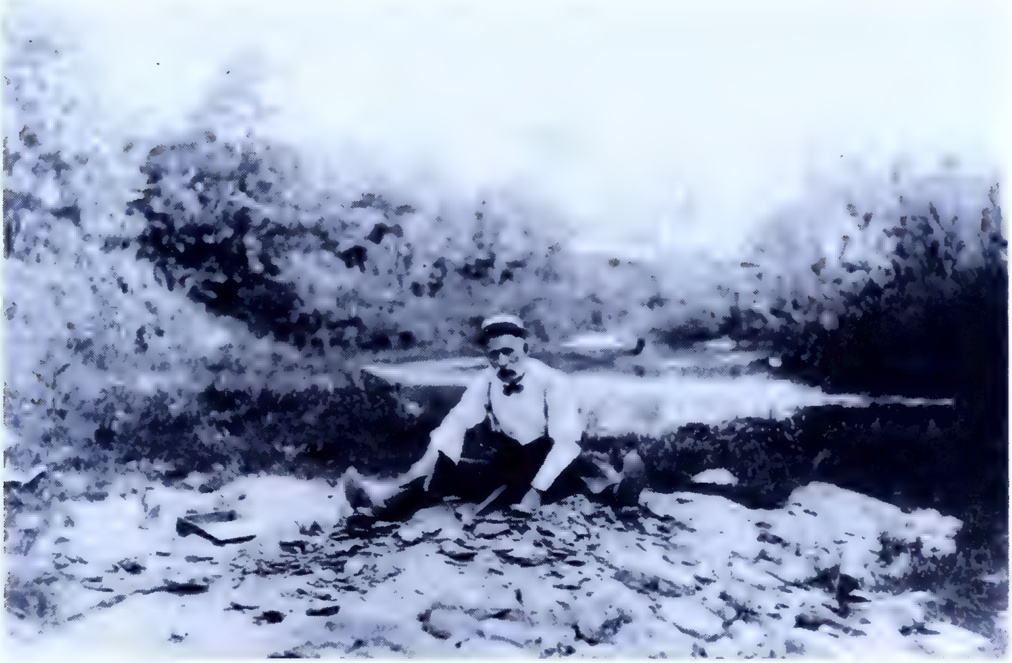


Figure 3. Dr. Robert Spangler Stahle sitting atop his bone bed at Zions View, York County, Pa., in 1910. The bone bed was rediscovered in 1970, and fossils were collected by Donald Hoff (former Earth Science Curator of The State Museum of Pennsylvania) and crew. A skull of the phytosaur *Rutiodon carolinensis* and a skull of the labyrinthodont amphibian *Buettneria perfecta* were collected along with other bones. Photograph courtesy of Harolld [sic] J. Stahle.

it turned up "in the course of future excavation." Sinclair wrote to Stahle (February 1911), "New knowledge cannot be valued in terms of dollars and cents, and these discoveries of yours are the newest and most important regarding Triassic dinosaurs which have been made in many years. I feel that the species should be named in your honor, *...stahlei* [italics are ours], a name by which your dinosaur would be known for all time to come...." This was an enticing lure that no doubt baited Stahle. Sinclair also promised to have the species described at the April meeting of the American Philosophical Society in Philadelphia and to place it on exhibit in the new Geological Museum at Princeton.

Figure 4. Princeton University paleontologist William J. Sinclair in 1923. Photograph courtesy of the Princeton University Geological Archives, Guyot Hall.

More correspondence ensued before any action was taken. We infer that Stahle was asking for more money because of the importance that Sinclair attached to this "dinosaur." Arguing that the material collected by Stahle was incomplete and that the fossil had limited research and exhibition value, Sinclair steadfastly held to the original negotiated price of $75. Realizing that no additional funds would be forthcoming, Stahle finally agreed to the original terms and sent the material to Princeton. With great anticipation, Sinclair waited to receive his "dinosaur" from the Triassic of York County.

The "paleontological bomb" dropped in March 1911, when Sinclair wrote to Stahle informing him that the specimen was not a dinosaur but was a phytosaur! Moreover, he referred it to the phytosaur genus *Rutiodon* and noted that it was similar to material found in North Carolina, except that it was larger. In his letter, Sinclair enclosed a tracing of McGregor's (1906) illustration (Figure 5) of *Rutiodon* (=*"Rhytidodon"*) *carolinensis* and colored in some of the bones corresponding to those that Stahle had found. These bones included both ilia (bones of the pelvis), left femur (thigh bone), two sacral vertebrae (vertebrae of the pelvis), anterior caudal (tail) vertebra, part of a trunk vertebra, a rib, rib fragments, osteoderms (bony plates), and fragmentary bones; numerous teeth were also found. The Stahle specimen (YPM PU–11544) belongs to the Princeton Collection, now housed at the Peabody Museum of Natural History of Yale University. It was, in part, incorporated into a panel mount of *Rutiodon* and is presently on loan to Rutgers University (Mary Ann Turner, personal communication, 1994).

The final disappointing blow was delivered in a subsequent letter, when Sinclair informed Stahle that his specimen was not a new species of phytosaur but belonged to the same species that had been described from the Palisades region of the Hudson River valley in New Jersey and named *Rutiodon manhattensis* (Sinclair, 1918). Shortly after that letter, collecting activities must have been suspended. We know from a letter from Sinclair to Stahle that there were some "legal or political complications" regarding the Zions View locality. We can only speculate about what precisely occurred. But we do know that the site fell into obscurity until 1970, when it was rediscovered and fossils were collected by personnel of The State Museum of Pennsylvania.

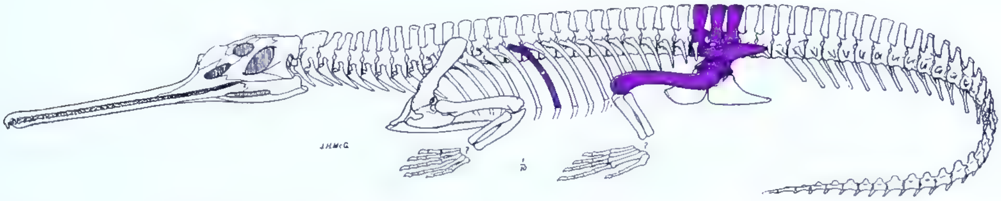


Figure 5. *Rutiodon* (="*Rhytidodon*") *carolinensis* as drawn by McGregor (1906) and as colored by Sinclair in his March 1911 letter to Stahle.

Under the direction of former Earth Science Curator Donald Hoff, the Zions View locality (the "Stahle Bone Bed") was worked from September 1970 through the fall of that year, and then again in the summer of 1971. Numerous disarticulated skeletal elements belonging to *Rutiodon carolinensis* (and the labyrinthodont amphibian *Buettneria perfecta*) were recovered during this time. The specimens collected are from more than one individual and represent a number of phytosaurs of different ontogenetic (growth) stages. Notable *Rutiodon* specimens from Zions View, housed in the collections of The State Museum, include a right ilium, numerous isolated teeth, osteoderms, a partial skull, parts of two lower jaws, and other skeletal elements.

It should be noted that, although the Zions View site was lost for more than a half century, other *Rutiodon* localities were discovered downstream along Little Conewago Creek, and fossils were collected from them between the time that Stahle abandoned Zions View and the early 1970's, when excavation was resumed there (Wanner, 1921, 1926). In addition, Huene (1921) reported other occurrences of phytosaur teeth from Pennsylvania at about the same time. It is likely that with continued interest and prospecting, we will find more phytosaur specimens, and perhaps one day, Pennsylvania's first dinosaur skeleton.

We thank Jon Inners of the Pennsylvania Geological Survey and Donald Hoff for reviewing this article; Mary Ann Turner of the Peabody Museum of Natural History, Yale University, for additional information about the original phytosaur specimen obtained by Princeton University; and Peggy Cross of Princeton University for the photograph of W. J. Sinclair. Special thanks are extended to Douglas Henderson for sending us a photograph of his phytosaur illustration and for allowing us to use it in this publication.

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Volcanic Ash Beds: One Person's Junk Is Another's Treasure

by Robert C. Smith, II
Pennsylvania Geological Survey

Depending on which person you ask, volcanic ash might be described as a treasure or junk. An agronomist might note the fertile soils that tend to form from volcanic ash after a few years of weathering releases plant nutrients such as potash, phosphorus, and sulfur. A climatologist might extol how volcanic sulfur dioxide gas protects the earth's atmosphere from warming caused by greenhouse gases. An aquatic biologist might describe damage to fisheries via hot volcanic mud in streams. An artist might be inspired by the enhanced color and beauty of sunsets caused by fine suspended ash. However, an astronomer might be disturbed by the reduced clarity of that same atmosphere a few hours later. A civil engineer might state the risks to life and property from mudslides of newly deposited ash. Finally, a geologist might tout the mineral-resource uses of ancient, now altered ash. Altered volcanic ash called bentonite has varied commercial uses, such as in well-drilling mud, in grout to seal water out of basements, or in impermeable barriers to toxic waste (Lefond, 1983). Bentonites also are commonly used as food additives (though they are not listed as ingredients in my favorite brands).

In several fields of geologic research, the occurrence of volcanic ash layers as time-line markers makes them very useful (Figure 1). Because the ash of a particular eruption fell over a wide area simultaneously, the ash layers can be used to correlate distant rock sections with accuracies as good as a few days, an unusual situation in geology, where uncertainties of a few million years are considered to be quite acceptable.

In Pennsylvania, the practical use of volcanic ash beds as marker layers is believed to have begun in the early 1930's, when the Tioga gas field of north-central Pennsylvania was developed. Fettke (1952) noted that the presence of a brown micaceous volcanic ash,

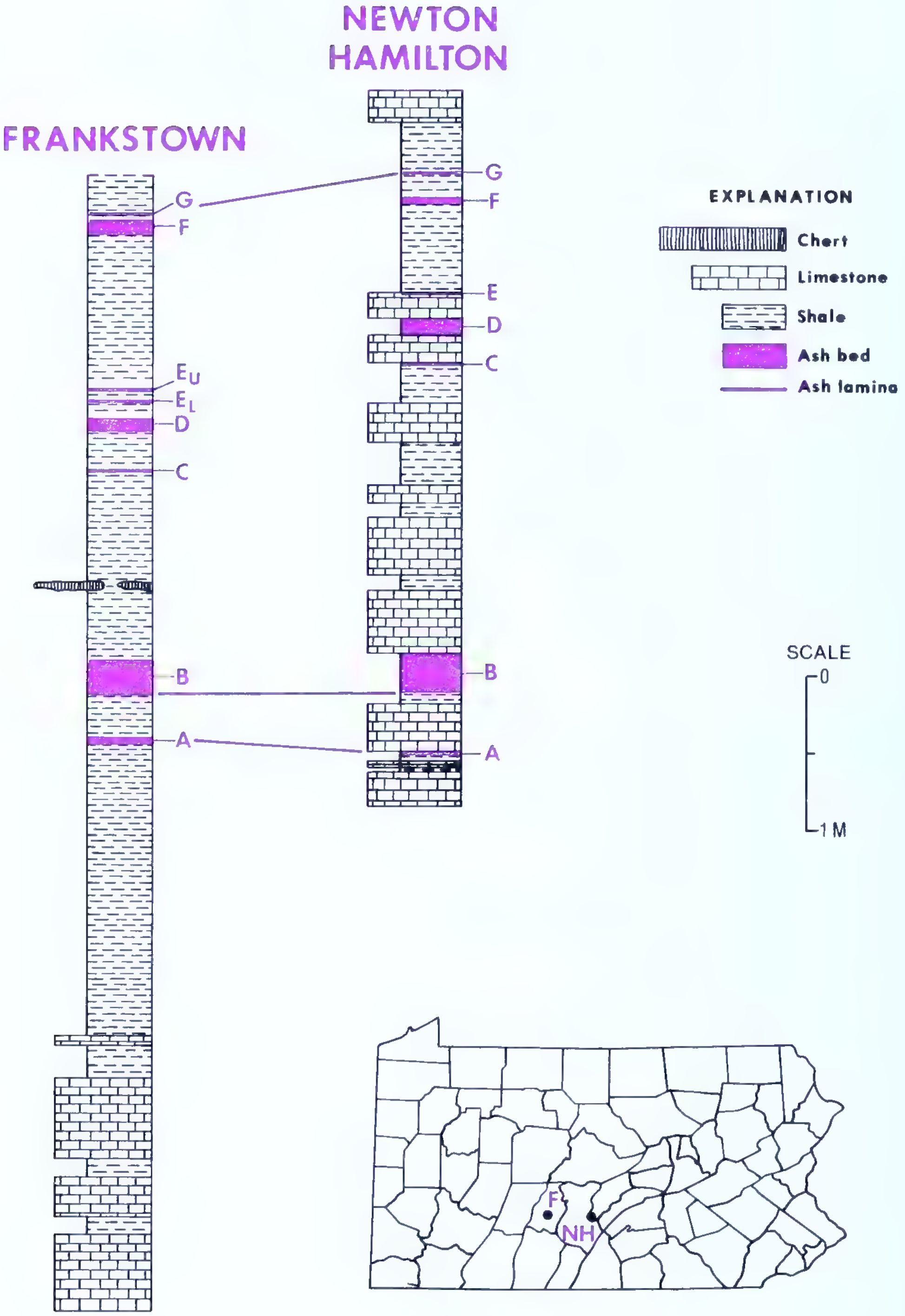

Figure 1. Example of the correlation of geologic time from Frankstown (F), Blair County, to Newton Hamilton (NH), Mifflin County. The match of seven ash layers, several having their own diagnostic properties, provides moderately strong scientific evidence that the two sections formed at corresponding times despite the much greater abundance of limestone at Newton Hamilton (modified from Way and others, 1986).

recovered during deep drilling, could be used to distinguish Onondaga limestone, which occurs just above the natural-gas-producing horizon, from similar-appearing Tully limestone, which occurs stratigraphically much farther above the producing horizon.

More recently, a pair of prominent volcanic ash beds near the contact between the Nealmont and Salona Formations in central Pennsylvania has served as a convenient reference point for locating samples from lower in the geologic section that are being studied for high-calcium-limestone potential. Once again, their value as marker layers is proven, even to being easily followed during quarrying or deep mining.

Short-range correlation problems on the scale of a few counties or states have largely been resolved for the Upper Ordovician, Lower Devonian, and Middle to Upper Devonian rocks by several geologists studying ash beds in Pennsylvania over the years. These were done mainly by verifying the identification of characteristic biotite crystals in the ash using a hand lens or by panning out unusually needlelike zircons from the altered ash layers. Intercontinental correlations of the Upper Ordovician bentonites are now in progress by W. Huff, S. Bergström, and D. Kolata. In a paper in the October 1992 issue of *Geology,* they suggested that the Millbrig ash bed that occurs in central Pennsylvania and large areas of central to eastern North America is the same as the “Big Bentonite” of Scandinavia. This correlation was based in large part on their chemical fingerprinting of scores of samples. What makes this correlation so interesting is that the eruption that produced the “Big Bentonite” redefines the term “large” when applied to a volcanic eruption. The authors reported that this eruption covered a few million square miles with a yard or two of ash. Altogether, the “Big Bentonite” eruption produced about 250 cubic miles of ash versus the recent eruption of Mt. St. Helens, Washington, which produced only 0.04 cubic mile of ash. Curiously, despite the burial of huge areas under ash, no significant extinction of fossil species has been recognized at the time of the “Big Bentonite” eruption.

Some other notable studies presently being done on ash beds in Pennsylvania include those by U.S. Geological Survey geologists, who are attempting to trace tonsteins (volcanic ash beds associated with coal measures) to help unravel Carboniferous stratigraphy in southwestern Pennsylvania; those of bentonites below the Tioga Ash Beds by Chuck Ver Straeten of the University of Rochester to refine Lower Devonian correlations; those by Mary Roden of Union College, Schenectady, N.Y., on regional erosion rates; those by George Shaw, also of Union College, on rare-earth fingerprinting to correlate apatites from bentonites; and analyses of volcanic melt trapped and preserved by growing quartz crystals recovered from several ash beds by John Delano and students at the State University of New York at Albany to correlate beds and locate source volcanoes.

In all, there are probably over a dozen researchers now studying volcanic ash beds in Pennsylvania. Exciting results are sure to follow!

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EARTH SCIENCE TEACHERS' CORNER

Fossils, Rocks, and Time

by Anne B. Lutz
Pennsylvania Geological Survey

The U.S. Geological Survey has published a 24-page booklet titled **Fossils, Rocks, and Time** by Lucy E. Edwards and John Pojeta, Jr., and a related poster, **Fossils Through Time**, by Pojeta and Edwards. Both the booklet and the poster were published in 1993 as part of a series of general interest publications. The authors introduce some of the basic concepts of biostratigraphy (the study of sedimentary rocks based on the fossils they contain) for a general audience. These publications would appeal to teachers who want to introduce students to fossils and sedimentary rocks, or to anyone new to this branch of geology.

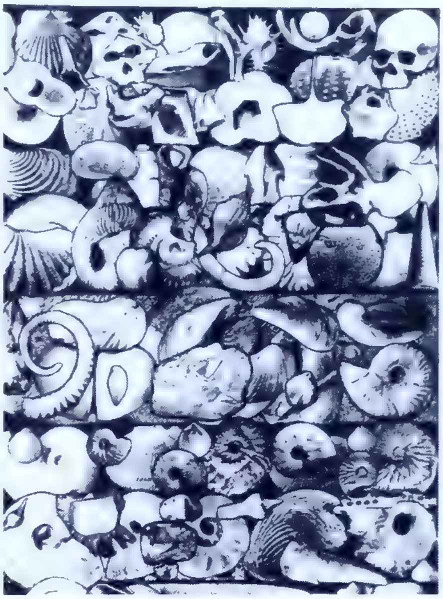
The text of the booklet flows smoothly from topic to topic, and a wide range of concepts is introduced. It begins with a description of the development and use of the relative geologic time scale. A discussion of rock age determinations using radioactive isotopes comes later, when the authors add numeric ages to the relative scale.

Another part of the booklet contains a description of how sedimentary rock layers, which preserve earth history, were formed. This explanation includes the names of scientists who derived some of the principles of biostratigraphy, which contributes to the reader's awareness of the historical development of this field.

The discussion of fossils includes the idea that there is a changing succession of fossils in the rocks, indicating that life on earth has changed through time. Other concepts, such as correlation, are presented in the illustrations and their accompanying captions. At the end of the booklet, a list of books for further reading is provided.

The booklet is filled with drawings and photographs, many of the photographs showing geologists at their jobs in both the laboratory and the field.

Fossils, Rocks, and Time



The poster by Pojeta and Edwards is a collage of photographs of fossils. The photographs are arranged by period along the geologic time scale, starting at 600 million years ago. Thus, the diversity and evolution of life on earth are represented. The first appearances of some fossil groups, the dominant organisms, and extinctions are explained in short texts that accompany each time period. However, the poster may give an unbalanced picture of the fossil record because it does not indicate which fossil groups were the most common in each geologic period.

Both the booklet **Fossils, Rocks, and Time** and the poster **Fossils Through Time** are available free of charge from Book and Open-File Report Sales, U.S. Geological Survey, Federal Center, P. O. Box 25425, Denver, CO 80225.

ANNOUNCEMENTS

New Editions of Bushkill and East Stroudsburg Topographic Maps Are Issued

The National Mapping Division of the U.S. Geological Survey (USGS–NMD), in cooperation with the Pennsylvania Geological Survey, has issued the first completely new editions of 1:24,000-scale topographic quadrangle maps of Pennsylvania with the 1993 release of the Bushkill and East Stroudsburg quadrangle maps of Monroe and Pike Counties (see back cover).

In 1973, the USGS–NMD completed 1:24,000-scale (7.5-minute) topographic map coverage of Pennsylvania through a 50/50 federal/state cooperative funding program. The state funds were provided by the Pennsylvania Geological Survey and the Pennsylvania Department of Transportation. This program began in 1946 and required 27 years before the last quadrangles (Canton in Bradford County and Union City in Erie County) were compiled, field checked, and printed. The 1:24,000-scale mapping program replaced an earlier topographic mapping program, never fully completed, that began in the 1880's to produce 1:62,500-scale topographic quadrangle maps (the 15-minute map series).

Of the 872 quadrangles that include significant areas within Pennsylvania, 824 (94 percent) have been revised, mostly as photorevisions, since 1973. These maps are familiar to users because of the purple overprint that indicates new roads, building structures, lakes, disturbed lands, and other features that have changed the appearance of the land area of the quadrangle since its original publication. With the release of the two new quadrangle maps, the Pennsylvania cooperative topographic map revision program, now funded by the Department of Environmental Resources, has reached a new milestone in its continuing efforts to maintain modern accurate standard-scale topographic maps of Pennsylvania.

The Bushkill and East Stroudsburg quadrangle maps were selected along with six other quadrangles (Pittsburgh East, Pittsburgh West, and four quadrangles in Clearfield County) for revision by replacement mapping either because there had been many changes to surface features or because the accuracy of the original map was no longer sufficient for modern-day usage.

For Pennsylvania, these two maps are also the first to be printed using the new North American Datum of 1983 (NAD83) to adjust the latitude and longitude position of the quadrangle map features and map corners. Modern use of satellites designed for locating geographic positions requires a more accurate, earth-centered, mathematical model to calculate site locations. This new model has resulted in shifting the former locations of corners (and depicted features) of quadrangle maps by various amounts. In Pennsylvania, the shift of quadrangle features and corners has been principally to the west and, to a lesser extent, south, by distances of from about 65 feet in western areas of the state to about 100 feet in eastern areas. A more detailed article on the shifting effect of the NAD83 on Pennsylvania quadrangle maps will appear in a future issue of *Pennsylvania Geology*.

Not all Pennsylvania quadrangles will be replaced in the manner of the new Bushkill and East Stroudsburg maps. Under the continuing map revision program, most quadrangle areas are photoinspected on a regular schedule and revised when necessary. "Limited update" (photorevision) is the most economical method of modernizing maps and suffices for most map revisions. Some maps that require more extensive revision, but for which most originally compiled information is accurate, are revised through the "standard" revision method, in which new features are added and contour changes are included in selected areas. Map feature changes normally shown in purple on a limited update map are depicted in standard map colors on standard revision maps. "Replacement" mapping is done only in areas where limited update or standard revision products do not meet user needs or accuracy requirements; it is the most expensive revision method. At the end of 1993, approximately 150 Pennsylvania quadrangles were in various stages and methods of revision.

Future joint revision program plans include modernization of Pennsylvania quadrangle maps using digital mapping techniques. At present, digital revision mapping projects are active for 29 Pennsylvania quadrangles, and the York quadrangle map will soon be released.

The new maps may be obtained for $2.50 each from the U.S. Geological Survey, Map Distribution Center, Federal Center, P. O. Box 25286, Denver, CO 80225 (please make checks payable to *Department of the Interior*), or by contacting one of the over 125 local Pennsylvania distributors of quadrangle topographic maps. More information on distribution may be obtained by calling 1–800–USA–MAPS. A list of local Pennsylvania distributors may be obtained by writing to the Pennsylvania Geological Survey, P. O. Box 8453, Harrisburg, PA 17105–8453.

Field Conference of Pennsylvania Geologists

The 59th Annual Field Conference of Pennsylvania Geologists, "Some Aspects of Piedmont Geology in Lancaster and Chester Counties, Pennsylvania," will be held from Thursday, September 29, through Saturday, October 1, 1994. The conference center will be in Lancaster, Pa. Attending geologists will consider these aspects of Piedmont geology: (1) facies relationships on the early Paleozoic carbonate shelf edge; (2) nature and provenance of the Peters Creek sediments; (3) implications of the geochemistry of the metabasalts; (4) patterns of regional metamorphism; (5) regional Alleghanian shear zones; (6) origin and transformation of the Cream Valley fault; (7) evolution of surficial deposits in southern Chester and Lancaster Counties; and (8) Late Cenozoic terraces along the lower Susquehanna River.

Thursday evening's activities will include registration, an introductory talk, and a reception. Friday will be spent mainly in Chester County. Saturday will be devoted mostly to visiting outcrops along the lower Susquehanna River. At least one preconference trip is planned.

A formal announcement of the conference, along with preregistration and hotel information, will be mailed in early August. If you have not attended a previous Field Conference and wish to receive the announcement for this year's meeting, please send a request to Field Conference of Pennsylvania Geologists, P. O. Box 1124, Harrisburg, PA 17108–1124.

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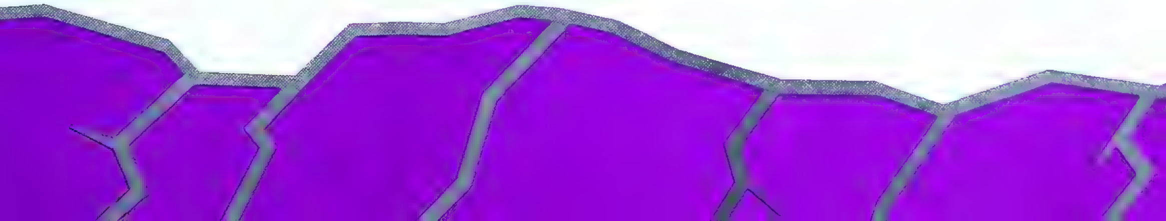
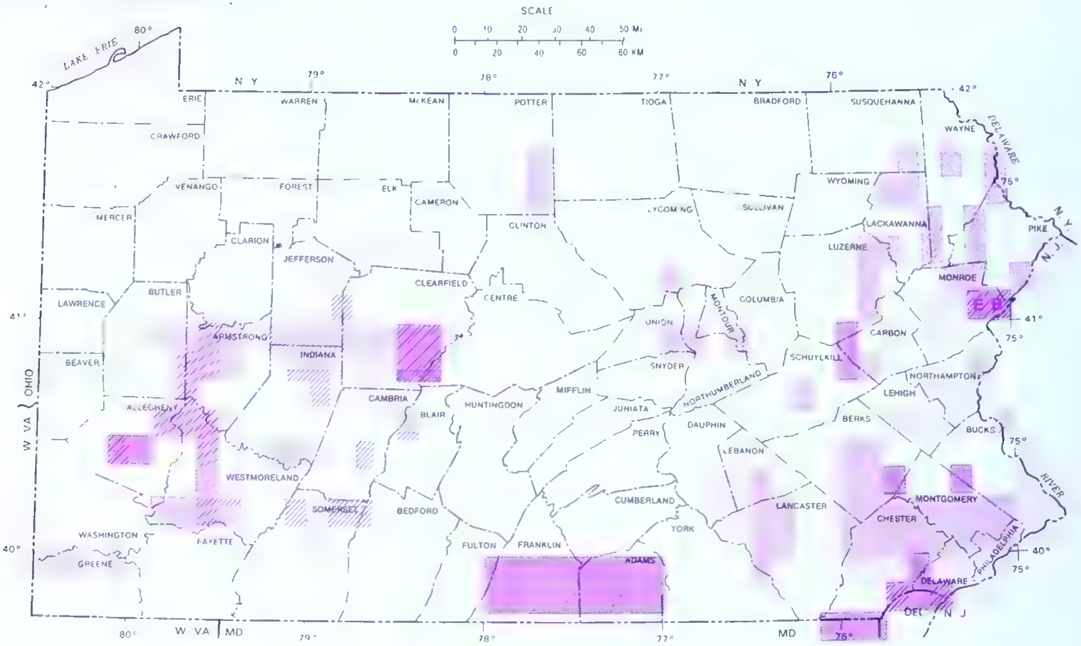


STATUS OF TOPOGRAPHIC MAP REVISIONS

(see article on page 14)



EXPLANATION

RECENTLY PUBLISHED	IN PROGRESS	
▨	■	Replacement-map projects (B, Bushkill quadrangle; E, East Stroudsburg quadrangle)
▨	■	Standard-update revision projects
▨	□	Limited-update revision projects

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ON THE COVER

The "stair-step" exposure of the Lower Conemaugh Pine Creek marine zone along the shoreline of the Youghiogheny River Lake, Confluence, Pa., locality 11 (see article on page 2). The outcrop was exposed due to the lowering of the lake level. Photograph by W. E. Kochanov.

PENNSYLVANIA GEOLOGY

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Editors: Christine M. Dodge, Anne B. Lutz, and Donald M. Hoskins.

Contributed articles are welcome; for further information and guidelines for manuscript preparation, contact D. M. Hoskins at the address listed above.

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The Fourth Pennsylvania Geological Survey at 75: 1919 to 1994

The present (Fourth) Topographic and Geologic Survey of Pennsylvania was created on June 7, 1919, when then Governor Sproul signed Act 205 into law. Although Governor Sproul's appointment letter to the first employee of the new Bureau was dated September 4, 1919, the work of the survey actually began on September 1, reflecting the urgent need of the day. On that date, Dr. George H. Ashley, widely respected for a lengthy career in both state and federal geological surveys, became State Geologist. He immediately began to deal with an accumulation of problems in Pennsylvania that required both an understanding of geology and the support of accurate topographic maps. His successors as State Geologists have been Ralph Stone, Stanley Cathcart, Carlyle Gray, Arthur Socolow, and myself.

During the succeeding 75 years, the staff of the Topographic and Geologic Survey of Pennsylvania has served the Commonwealth by providing answers to problems that require an understanding of the geology and topography of our state. The Bureau has served Pennsylvania citizens by responding to uncounted thousands of requests for specific geological and topographic information and for explanations of the many geological features and phenomena present in our Commonwealth. In order to provide reliable scientific information supporting these responses, the Bureau has independently conducted or assisted in extensive field investigations in all areas of the Commonwealth. These investigations include the collection of geologic data concerning the location and nature of Pennsylvania's rocks and surficial materials and their energy, mineral, and water resources. The data have been analyzed, synthesized, and provided to the public through detailed, as well as popularly written, reports and maps. The number of reports and maps issued since 1919 now totals nearly 900.

These accomplishments are the result of 75 years of work by dedicated and competent geologists and support staff of the Bureau, for whom public service has a high personal value, following the principles established by Dr. Ashley. Their work and the products of the Bureau have been complemented by the efforts of the larger community of geologists who investigate and analyze the complex geology of

(continued on page 15)

HOOKED ON THE ROCKS: Exploring the Geology of the Youghiogheny River Lake—A Boating Field Trip

by James R. Shaulis
Pennsylvania Geological Survey

You are out fishing one morning on the Youghiogheny River Lake. As the sun begins to rise, you make your first cast of the day. Trying to drop your lure near the steep rocky shore, you accidentally overthrow. Your lure becomes wedged in a rock crevasse so tightly that you are forced to go ashore to free it. When you bend down to retrieve it, you notice that some of the rock layers contain many different types of marine fossils. Other rock slabs that have slid down from above have rippled surfaces, and a few are also marked with sinuous wormlike trails. When you look up to see where these rocks came from, you notice that higher up on the shoreline, the rocks change in color from pale olive to grayish red. You have many questions about what you see here. If the answers could be found on a boating excursion that included beautiful scenery, fishing, fossil hunting, and a basic introduction to the various types of sedimentary rocks and the geologic history of western Pennsylvania, would that be a catch worth keeping? If so, cast your eyes on this article and reel it in.

THE CREATION, CARE, AND MAINTENANCE OF AN OUTCROP. The Youghiogheny River Lake (YRL) (Figure 1) was completed by the U.S. Army Corps of Engineers in 1943 in conjunction with the Flood Control Act of 1938. The YRL provides flood protection and also is a water supply for downstream communities and commerce. Its water level is adjusted continuously by the Corps of Engineers according to a schedule that takes into account seasonal precipitation amounts in the YRL watershed. On the average, the level is adjusted by 0.5 foot per day up or down over a 50-foot range between 1,390 feet and 1,440 feet above mean sea level. However, during very wet or very dry periods, the range can increase by 20 feet in either direction. The right-hand column of Table 1 contains a listing of water levels by month for an average precipitation profile based on records for the past 30 years.

Before the YRL existed, the Youghiogheny River cut a deep gorge-like valley hundreds of feet deep across the landscape of this area. Field notes of geologists who mapped in the region indicated

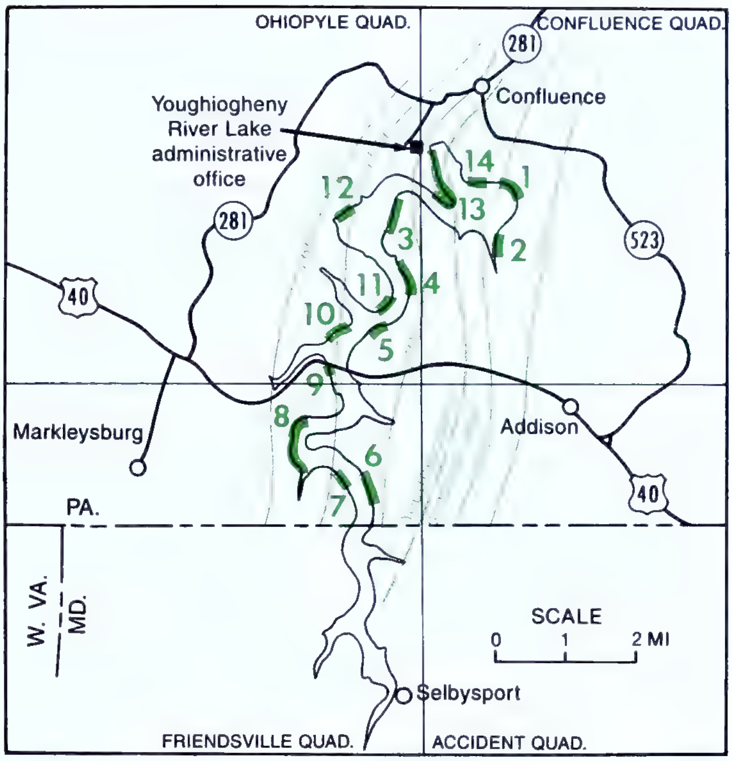

Figure 1. Map showing the location of rock exposures along the Youghiogheny River Lake shoreline and structure contours on the basal coquina limestone of the Pine Creek marine zone.

that few natural rock exposures existed, except for some resistant sandstone ledges. Most of the rocks in this area were covered by thick vegetation, soil cover, and talus.

However, since the construction of the lake, rocks have become exposed, especially on the steeper outside cut banks of the former Youghiogheny River. The continuous raising and lowering of the water level has effectively stripped away the soil and vegetation from those areas to expose the rocks. Once exposed, the rocks are swept clean of sediment by wind and powerboat-generated wave action. The natural slope and the daily incremental change in water level has created a stairstep outcrop pattern, which provides many opportunities for examining beds in a three-dimensional perspective (see cover photograph). During the spring and summer months, the rocks are completely submerged; in late summer to late fall, they are exposed and washed clean before being subjected to many freeze/thaw cycles during the beginning of winter. This yearly sequence of events has greatly accelerated the weathering of these rocks and has kept the outcrops uncovered and fresh like a rocky ocean shoreline, so that today, with the combined efforts of man and nature, miles of pristine rock exposures exist where none had been before. Figure 1 shows the locations of the 14 best-developed outcrops on the YRL shoreline in Pennsylvania.

OBSERVATIONS AND INTERPRETATIONS OF THE ROCKS. The YRL lies completely within the Youghiogheny synclinal structure. The axis of this syncline trends northeast-southwest and intersects

Table 1. ***Months When the Base of a Stratigraphic Interval is Exposed Above the YRL Shoreline in a Year Having Average Rainfall***

	Locality number														
Mo.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Lake elev.[1]
J	n pc	n pc	n pc	n pc	pc	n pc	b	m	b	b	n pc	b	wr	wr	1,400
F	n pc	n pc	n (pc)	n pc	pc	n pc	b	m	b	b	n pc	b	wr	wr	1,410
M	n (pc)	n	n	n pc	pc[2]	n (pc)	b	m	b	b	n pc	b	wr	wr	1,420
A		n[2]	n[2]		pc[2]	n[2]	b[2]	m[2]	b		n[2]				1,437
M		n[2]	n[2]		pc[2]	n[2]	b[2]	m[2]	b		n[2]				1,440
J		n[2]	n[2]		pc[2]	n[2]	b[2]	m[2]	b		n[2]				1,440
J	n	n	n		pc	n[2]	b[2]	m[2]	b		n[2]				1,438
A	n	n	n		pc	n	b	m	b	(b)	n				1,433
S	(pc) n	n	(pc) n	(pc) n	pc	(pc) n	b	m	b	b	n pc	b	wr	wr	1,421
O	n pc	n pc	n pc	n pc	pc	n pc	b	m	b	b	n pc	b	wr	wr	1,407
N	n pc	n pc	n pc	n pc	pc	n pc	b	m	b	b	n pc	b	wr	wr	1,394
D	n pc	n pc	n pc	n pc	pc	n pc	b	m	b	b	n pc	b	wr	wr	1,395

[1] Elevations are for the first day of each month.

[2] Base of interval is just above water level.

( ), Only exposed for half of the month.

m, Mahoning coal and sandstone; b, Brush Creek coal and marine zone; pc, Pine Creek marine zone; n, Nadine marine zone; wr, Woods Run marine zone.

the shoreline of the YRL at locality 13 (Figure 1). Its southeastern limb can be seen dipping gently 1 degree to the northwest toward the axis at locality 1. The dip on the northwestern limb varies from 1 to 2.5 degrees to the southeast but is hard to see because most of the outcrops on this side of the syncline are oriented parallel to strike.

The exposed stratigraphic sequence totals about 230 feet along the YRL shoreline and contains four discrete intervals: (1) the Mahoning coal and sandstone interval; (2) the Brush Creek coal and marine zone interval; (3) the Pine Creek and Nadine marine zone interval; and (4) the Lower Bakerstown coal and Woods Run marine zone interval (Figure 2). Composite columnar sections and interpretations of depositional environments for each interval are shown in Figure 3. The depositional history for each interval is briefly discussed below, in ascending stratigraphic order.

A. Mahoning Coal and Sandstone Interval (Locality 8). The Mahoning coal and sandstone interval is the only nonmarine sequence occurring along the lake. It makes up the longest continuous outcrop, nearly 1 mile in length.

After a river that was flowing across a deltaic plain deposited the Lower Mahoning sandstone, it migrated out of the area. A slow

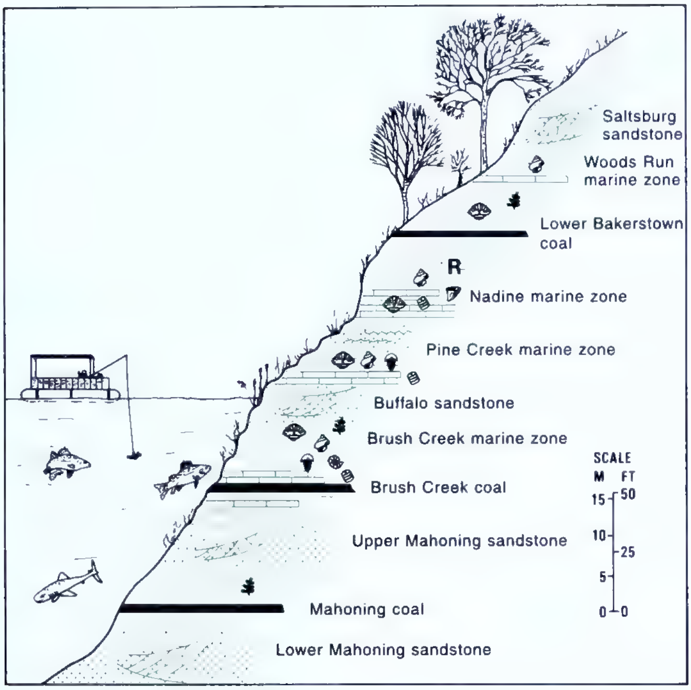

Figure 2. Composite columnar section of Upper Pennsylvanian rocks (Glenshaw Formation, Lower Conemaugh Group) exposed along the YRL shoreline. The sketch shows rock units exposed at locality 1 in mid-September in an average rainfall year. The fish under the boat are rock bass and freshwater sandstone sharks. See Figure 3 for explanation of symbols and patterns.

subsidence of the land then occurred, and large, shallow, poorly drained depressions developed. This provided an ideal setting for plant growth and the development of a peat swamp that eventually became the Mahoning coal. The swamp was then covered with clay, organic debris, and silt from overbank deposits of a nearby fluvial system. Finally, another river meandered back into the area and deposited the Upper Mahoning sandstone at the top of the section. A generalized diagram illustrating depositional environments common to a Pennsylvanian delta is shown in Figure 4. Of special interest is the upper portion of the Mahoning coal seam, which contains well-preserved sideritized *Stigmaria* fossils up to 0.8 inch wide and 3.0 feet long.

B. Brush Creek Coal and Marine Zone (Localities 7, 9, 10, and 12). The Brush Creek coal and marine zone is exposed at four separate localities on the western shoreline of the YRL.

The freshwater limestone at the base of the section is interpreted to have been deposited in a freshwater pond or lake. As this lake filled with lime mud and fine noncarbonate sediments, the water shallowed, allowing plant growth, and the area evolved into a swamp that accumulated peat, which eventually formed the Brush Creek coal. A rise in sea level led to a marine transgression over the swamp, transforming the area into a restricted interdistributary bay. In this environment, dark fossiliferous shales and thin coquina limestones containing a nearshore marine fauna were deposited. Land was close by, as indicated by the presence of crinoid columnals and

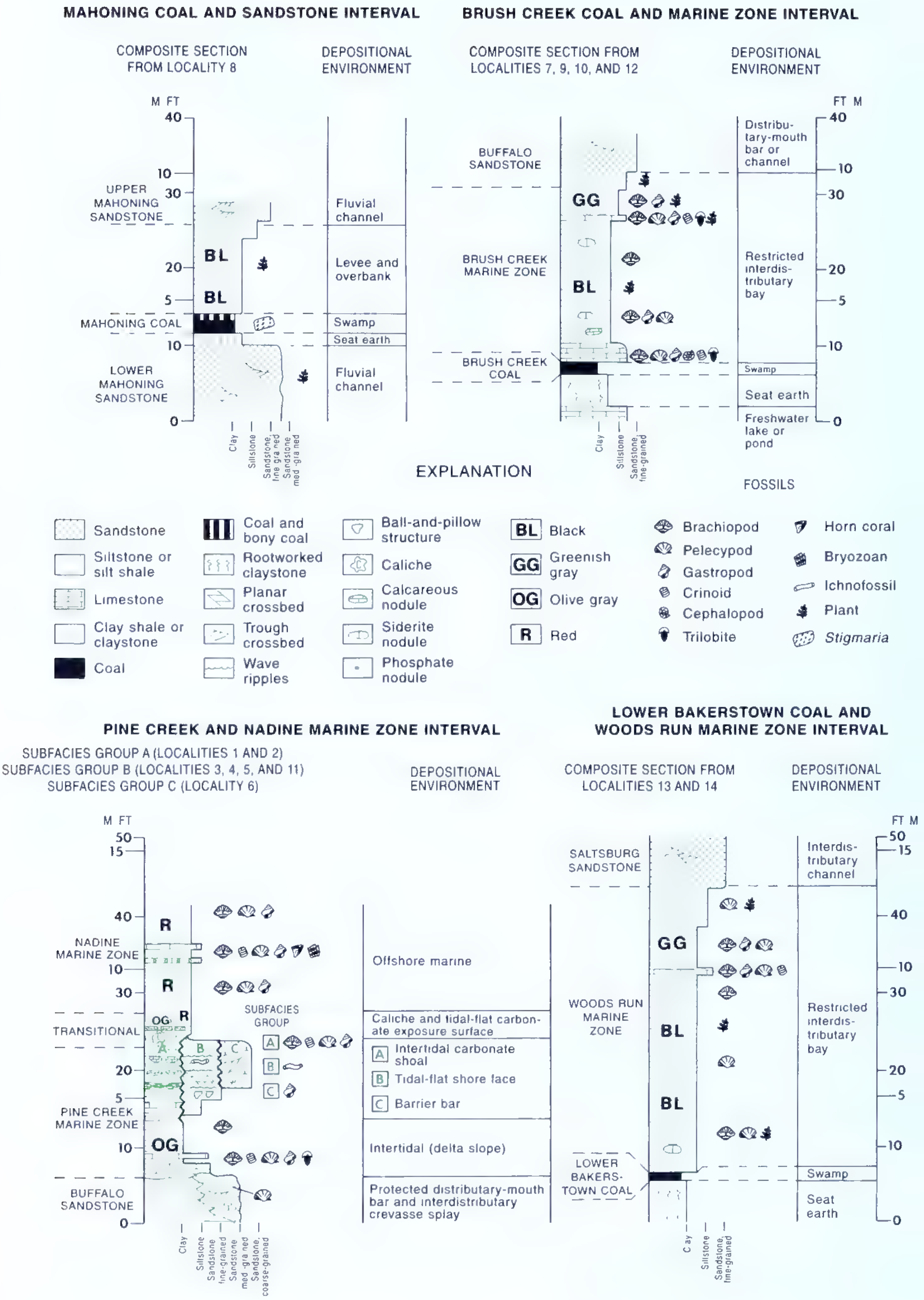

Figure 3. Composite columnar sections of rock exposures found along the Youghiogheny River Lake and their interpreted depositional environments.

intact fern fronds together in one of the coquina limestone beds. As the interdistributary bay continued to fill with sediment and prograde seaward, a coarsening-upward sequence of rocks was deposited that culminated with the Buffalo sandstone.

C. The Pine Creek and Nadine Marine Zones (Localities 1, 2, 3, 4, 5, 6, and 11). The Pine Creek-Nadine marine zone interval is exposed at seven different localities covering more than 2 miles of the YRL shoreline.

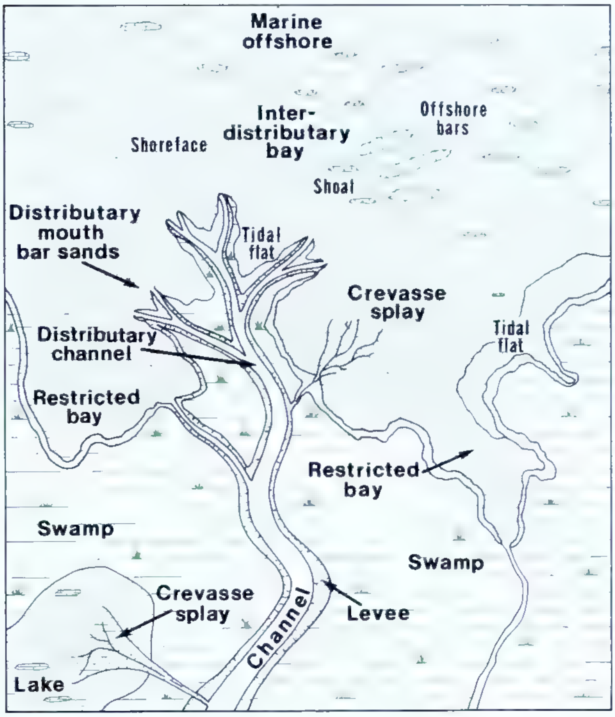

Figure 4. Generalized diagram showing depositional environments common to a Pennsylvanian delta (modified from Flores and Arndt, 1979). See Figure 3 for explanation of patterns.

The sediments underlying the Pine Creek were formed either in an interdistributary bay environment by a distributary-mouth bar (locality 1 only) or as crevasse-splay deposits. A subsequent rise in sea level resulted in a marine transgression. The coquina limestone and fossiliferous shales (Figures 5A, 5C, and 5D) at the base of the Pine Creek represent the initial transgressive phase. Following this phase, a shallowing of the water occurred as the land prograded seaward. This is reflected in a gradual coarsening-upward pattern in the Pine Creek. However, in the upper portion, this trend is also accompanied by complex lateral facies changes in what is interpreted as a nearshore intertidal environment. Within this intertidal setting, the following subfacies groups have been identified: intertidal carbonate shoal (group A), tidal-flat shore face (group B), and barrier bar (group C)(Figure 3).

Following the deposition of the Pine Creek in a nearshore intertidal environment, a drying out occurred, as indicated by the appearance of caliche beds. After subaerial exposure of the land, marine conditions returned and resulted in the deposition of a red clay shale interbedded with thin limestones, called the Nadine marine zone. The presence of crinoids (Figure 5B), corals, bryozoans, and phosphate nodules in the limestones and brachiopods in the red shales, and

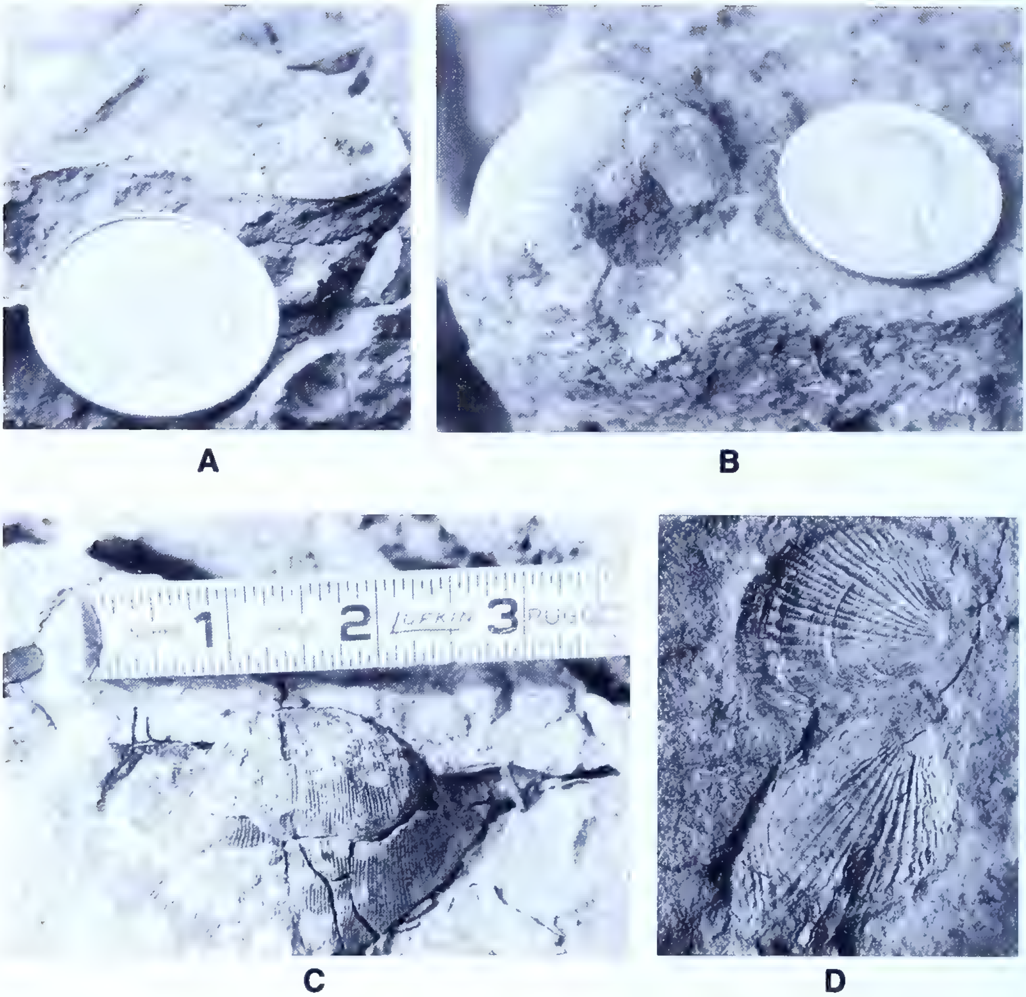

Figure 5. Photographs of fossils found in the rocks along the YRL shoreline. A, Trilobite pygidium in basal coquina limestone of the Pine Creek marine zone from locality 5. B, Crinoid calyx found in the Nadine limestone at locality 3. C, Large "adult" *Juresania* sp., a brachiopod from the basal Pine Creek at locality 11. D, *Dunbarella* sp., a brachiopod from the lower Pine Creek shale at locality 11. The length of the large valve is 25 mm.

the lack of any coarse-grained siliciclastics in the Nadine interval indicate that it was deposited in an offshore marine setting. The red color of the clay shale may have resulted from the erosion of a reddish, iron-rich soil into the marine depositional environment.

D. The Lower Bakerstown Coal and Woods Run Marine Zone (Localities 13 and 14). This interval is lithologically nearly identical to the Brush Creek coal and marine zone and is interpreted to have a similar depositional history (Figure 3).

PLANNING YOUR VISIT TO SEE THE SITES. Before planning to visit any of the outcrop localities along the lake, first check the exposure chart shown in Table 1 to see which sites are exposed at that time of year. Better yet, contact the Army Corps of Engineers at YRL to find out if the current lake level corresponds to the level shown on the chart. Otherwise, determine what sites are accessible by finding the month on the chart in which the lake level is approximately the same as the current lake level. The best time to examine all of the outcrops is in late summer to late fall when water levels are lowest.

To get to the outcrops, pontoon boats are available for daily rental at the Youghiogheny Lake Marina from June 1 through the middle of September. However, all outcrops are accessible by car and foot for the truly determined. Before attempting to do this, consult the 7.5-minute-quadrangle map of the area. Many roads that encircle the lake are narrow semiprivate routes having limited off-road parking. If you are near a private residence, it is advisable to ask permission before leaving your car parked for an extended period. WARNING: The lake is surrounded by steep slopes and cliffs that are made up of highly weathered, incompetent rocks. Vertical drops of more than 20 feet occur along the shoreline in many areas. The author can assure you that access via this route can be very quick, but very painful, so use extreme caution if you go down to the shoreline on foot in these areas.

THE END OF THE LINE. The sun has now almost set, but it seems as though only an hour has passed. You have visited ancient oceans, coastlines, bays, rivers, and swamps without leaving the shoreline of the Youghiogheny River Lake. You have marveled at how the natural geologic processes and man's presence have changed and continue to change the landscape over time.

When you finally arrive back home, a family member comments on how the fishing must have been good today because you are home so late. Not having any fish to show off, you reply, "Well you see, what happened is that, while I was fishing, I got hooked on some rocks and I just couldn't get loose."

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Sedimentary Evaporites in the Gatesburg Formation of Central Pennsylvania

by Christopher D. Laughrey
Pennsylvania Geological Survey

> *"It's these changes in latitude...*
> *nothing remains quite the same."*
> —Jimmy Buffet, 1976

INTRODUCTION. The winter of 1993–94, with no fewer than 16 snowstorms, caused many a Pennsylvanian to dream about balmy southern climes and tropical shores. While shovelling through the drifts left in my driveway by a hydrologic cycle gone berserk, I tried to find consolation in the fact that the Keystone State once lay near the equator. A little more than 500 million years ago, Pennsylvania resembled the Bahamas, although it was probably much drier. Drifts of sand rather than snow lined the shore, and often, much of the water available there evaporated, leaving behind only a mineral legacy.

THE GATESBURG FORMATION AND "GREAT AMERCAN BANK." Rocks of Late Cambrian age in the Gatesburg Formation of central Pennsylvania are part of a thick regional succession of platform carbonates that accumulated on the southwest-facing coast of the ancient continent called Laurentia, which was positioned athwart the equator (see back cover). The Cambrian and Ordovician Periods were times of widespread carbonate deposition in what would later become North America. Broad carbonate shelves extended along the lengths of what would become the Appalachians in the east and the Rockies in the west (Hardie, 1986, p. 40). In the area of the future Appalachians, this Cambrian and Ordovician platform produced a wedge of carbonate rocks more than 1,860 miles long, more than 186 miles wide, and as much as 2.2 miles thick (Colton, 1970)! It is one of the largest accumulations of carbonate sediments in the geologic record (Hardie, 1986), an accumulation that the eminent carbonate geologist R. N. Ginsburg (1982) christened the "Great American Bank" (similar to the modern Great Bahama Bank).

In central Pennsylvania, the Gatesburg Formation consists of repeated (cyclic) sequences of peritidal carbonates, noncyclic subtidal carbonates, and two rather prominent quartz-sandstone zones. The cyclic peritidal carbonates exhibit well-defined shallowing-upward tidal-flat sequences, as schematically illustrated in Figure 1.

ANCIENT CLIMATES. Paleogeographic and paleo-oceanographic placement of the Laurentian landmass indicates that the climate was probably semiarid during deposition of the Upper Cambrian rocks of central Pennsylvania. Because the southwest-facing coast of Laurentia lay between 0 and 30 degrees south latitude (see back cover), the dominant wind pattern likely was a southeasterly trade wind that carried warm maritime air from the moist western side of a high-pressure center in the Iapetus Ocean (Riley and others, 1993, p. 11–12). This air movement would have provided abundant rainfall along the east coast of Laurentia, but the southwest coastal climate would have been relatively dry and similar to those of modern-day Morocco, Baja California, and western Australia (Wilde, 1991; Riley and others, 1993).

The geological evidence for a semiarid setting is mostly indirect. Shallowing-upward tidal-flat sequences in the Gatesburg Formation contain several indicators of subaerial exposure and desiccation, such as mudcracks and intraclast chips in association with isolated, displacive nodules of sparry calcite. Hardie (1986) and Read (1989) interpreted the calcite nodules as former anhydrite nodules formed in the supratidal zone.

EVAPORITES. The Pennsylvania Geological Survey recently participated in a two-year multidisciplinary research program designed to measure and predict petroleum reservoir heterogeneity in Upper Cambrian rocks in Pennsylvania and Ohio (Riley and others, 1993). During this work, Survey geologist John Harper and I were surprised and delighted to find sedimentary evaporites in core samples of the Gatesburg Formation.

The Shell Oil Company drilled the Shade Mountain #1 well in Fayette Township, Juniata County, in 1964. One of the cores recovered from this well consists of almost 26 feet of dolostone and a 4-foot-thick sequence of sedimentary anhydrite near the top (Figures 1B and 2). The anhydrite occurs between depths of 10,013 and 10,017 feet. The lowest part of the anhydrite zone in the core is transitional with subjacent oolitic, fossiliferous, mottled, and burrowed dolostone.

The bulk of the evaporite in the core consists of moderate-yellowish-brown, slightly dolomitic anhydrite. The anhydrite displays wavy, anastomosing, and laminated bedding. It also contains very thin, discontinuous and wispy, nonparallel laminations of finely crystalline dolomite intercalated with micron-sized, subhedral crystals of

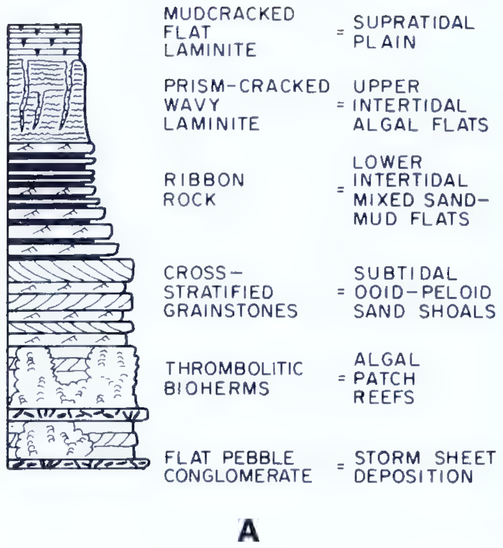
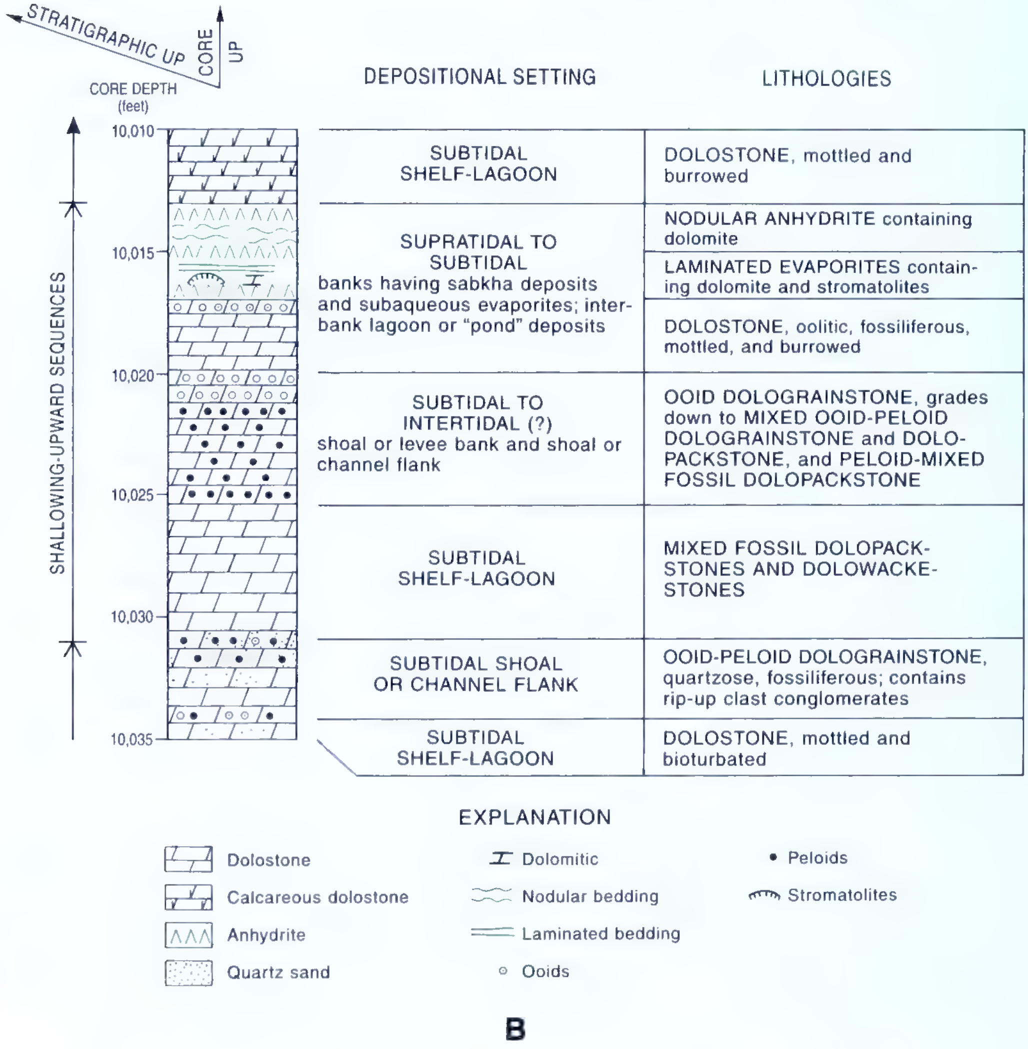

MUDCRACKED FLAT LAMINITE = SUPRATIDAL PLAIN
PRISM-CRACKED WAVY LAMINITE = UPPER INTERTIDAL ALGAL FLATS
RIBBON ROCK = LOWER INTERTIDAL MIXED SAND-MUD FLATS
CROSS-STRATIFIED GRAINSTONES = SUBTIDAL OOID-PELOID SAND SHOALS
THROMBOLITIC BIOHERMS = ALGAL PATCH REEFS
FLAT PEBBLE CONGLOMERATE = STORM SHEET DEPOSITION
A

Figure 1. Shallowing-upward carbonate sequences are stratigraphic successions in which each unit was deposited in progressively shallower water. These successions are repeated many times within a stratigraphic section of shallow-water carbonate rocks. A, Lithologies and interpreted depositional environments of several sedimentary subfacies in shallowing-upward sequences found in Cambrian and Ordovician rocks in the central Appalachians (from Hardie, 1986). B, Graphical core description of the Gatesburg Formation in the Shade Mountain well, Juniata County (modified from Riley and others, 1993). The core contains repeated shallowing-upward sequences. Note the presence of anhydrite near the top of the core.


STRATIGRAPHIC UP
CORE UP
CORE DEPTH (feet)
10,010
10,015
10,020
10,025
10,030
10,035
SHALLOWING-UPWARD SEQUENCES
DEPOSITIONAL SETTING
LITHOLOGIES
SUBTIDAL SHELF-LAGOON
DOLOSTONE, mottled and burrowed
SUPRATIDAL TO SUBTIDAL banks having sabkha deposits and subaqueous evaporites; interbank lagoon or "pond" deposits
NODULAR ANHYDRITE containing dolomite
LAMINATED EVAPORITES containing dolomite and stromatolites
DOLOSTONE, oolitic, fossiliferous, mottled, and burrowed
SUBTIDAL TO INTERTIDAL (?) shoal or levee bank and shoal or channel flank
OOID DOLOGRAINSTONE, grades down to MIXED OOID-PELOID DOLOGRAINSTONE and DOLOPACKSTONE, and PELOID-MIXED FOSSIL DOLOPACKSTONE
SUBTIDAL SHELF-LAGOON
MIXED FOSSIL DOLOPACKSTONES AND DOLOWACKESTONES
SUBTIDAL SHOAL OR CHANNEL FLANK
OOID-PELOID DOLOGRAINSTONE, quartzose, fossiliferous; contains rip-up clast conglomerates
SUBTIDAL SHELF-LAGOON
DOLOSTONE, mottled and bioturbated
EXPLANATION
Dolostone
Calcareous dolostone
Anhydrite
Quartz sand
Dolomitic
Nodular bedding
Laminated bedding
Ooids
Peloids
Stromatolites
B

anhydrite (Figure 3). Coarser anhydrite in this part of the sequence consists of subhedral crystals ranging in size from 0.03 to 0.75 mm in diameter (Figure 3).

The upper part of the anhydrite sequence in the Shade Mountain well core consists of light-olive-gray to yellowish-gray nodular anhydrite. The change from laminated to nodular bedding is transitional, and a zone of decreasing lamination and crystal size occurs between the laminated and nodular intervals. The laminae in the transitional zone are indistinct, and some nodules appear within the laminae. Distinct nodules in the upper part of the sequence consist of aggregates of subhedral anhydrite crystals in a groundmass of micron-sized dolomite. The latter contains the microfossils *Epiphyton* (a calcareous red alga) and *Renalcis* (a cyanophyte, or "blue-green alga"). These remnants of mound-building organisms are common in Cambrian and Ordovician rocks of the central Appalachians.

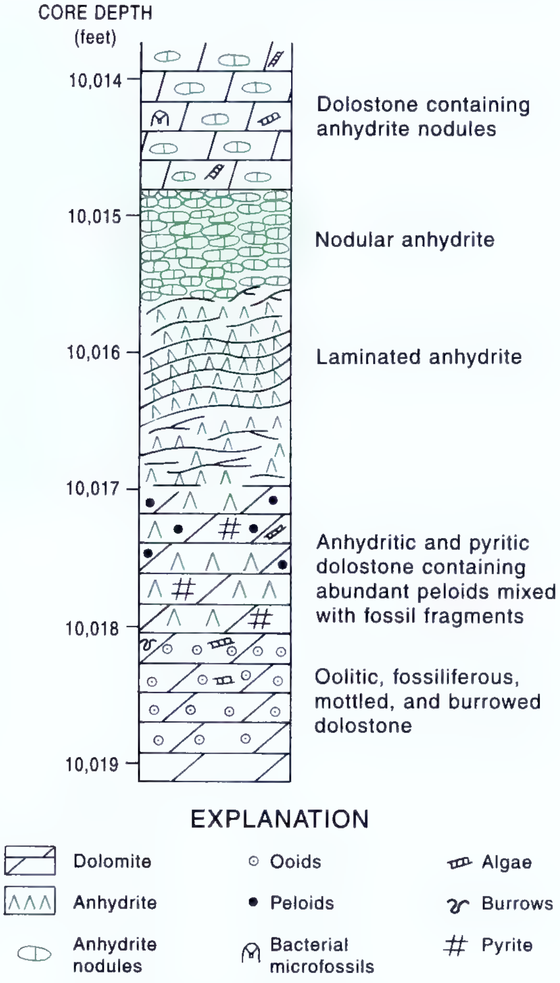


Figure 2. Detailed description of the anhydrite interval from near the top of the core shown in Figure 1.

The anhydrite in the Shade Mountain well core exhibits two principal habits, laminated and nodular. Nodular anhydrite is a common habit in both modern and ancient evaporite deposits, and its presence is a key factor in the recognition of paleosabkhas in the rock record (Tucker, 1981; Kendall, 1984). Laminated anhydrite has been variously interpreted as basinal varves, algal mats, or coalescing nodules. Nodular and laminated anhydrite commonly occur together, and both form subaqueously in shallow or deep standing water (Dean and others, 1975). The sequence in the Shade Mountain well core occurs within well-defined cyclic peritidal deposits and

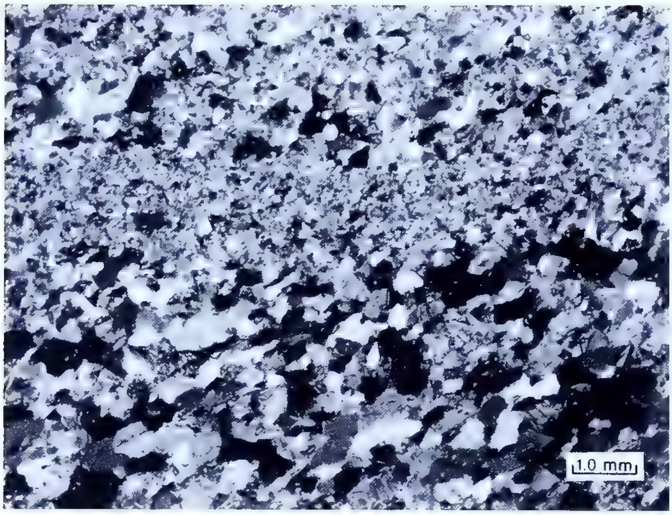
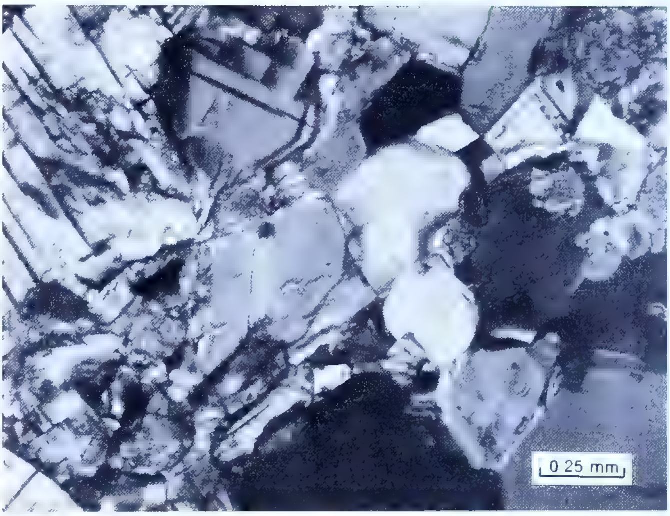


Figure 3. Thin-section photomicrographs of the laminated anhydrite in the Shade Mountain well core. A, Low magnification reveals the laminated habit of the anhydrite. B, Higher magnification shows the crystal texture in the coarser laminae.

can be confidently interpreted as having been produced on a tidal flat (Figure 1). The evaporites in the Shade Mountain core probably formed along the high portion of a carbonate bank or in interbank ponds and lagoons as subaqueous evaporites.



Although the specific mechanism of original evaporite precipitation and subsequent diagenetic alteration of these beautiful anhydrites in the Shade Mountain core remain to be proven, the fact that unambiguous sedimentary evaporite minerals do occur in Upper Cambrian rocks of central Pennsylvania helps to support published paleoclimatic interpretations of ancient continents. This occurrence of anhydrite in the Gatesburg Formation provides direct evidence of at least semiarid, and perhaps actual arid, conditions during Late Cambrian time on the southwest-facing coast of Laurentia.

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The Fourth Pennsylvania Geological Survey at 75: 1919 to 1994

(continued from page 1)

Pennsylvania. Although the tasks ahead will be even more demanding as increased use is made of Pennsylvania's land surface and earth resources, on this occasion of the Survey's 75th anniversary, I commend the past and present geologists, hydrogeologists, and technical and administrative assistants of the Pennsylvania Bureau of Topographic and Geologic Survey for jobs very well done!

Donald M. Hoskins

Donald M. Hoskins
State Geologist

The Carpenter's Level as a Geomorphological Teaching Tool

by William Kreiger
Physical Sciences Department, York College
York, PA 17405–7199

As part of an introductory laboratory mapping exercise that utilizes road maps, topographic maps, and raised-relief maps of Pennsylvania, the students observe the mountains in the Ridge and Valley physiographic province on all maps. After they look at the ridges on the "flat" maps, they place a carpenter's level on the mountaintops in both the north-south and northwest-southeast directions at several locations on the Hubbard NK18–10 Harrisburg raised-relief map, which has a scale of 1:250,000. The students find that the level indicates that the tops of the mountains are all at about the same elevation. The bubble indicates that these tops form a level surface. Even though the students can see from the topographic maps that the elevations are quite close, the simple act of placing a carpenter's level on the raised-relief map does wonders for their comprehension. This new awareness opens the door for discussion of peneplains versus rock resistance and other aspects of erosion that produced this topography.

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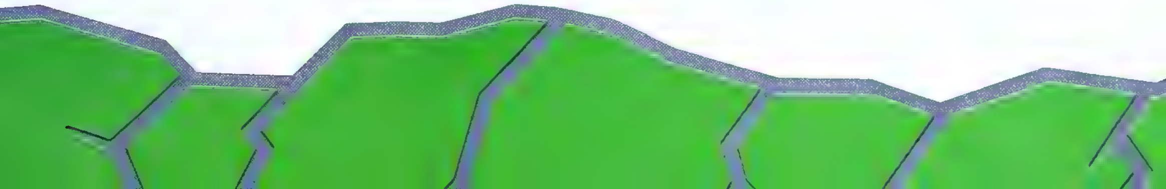
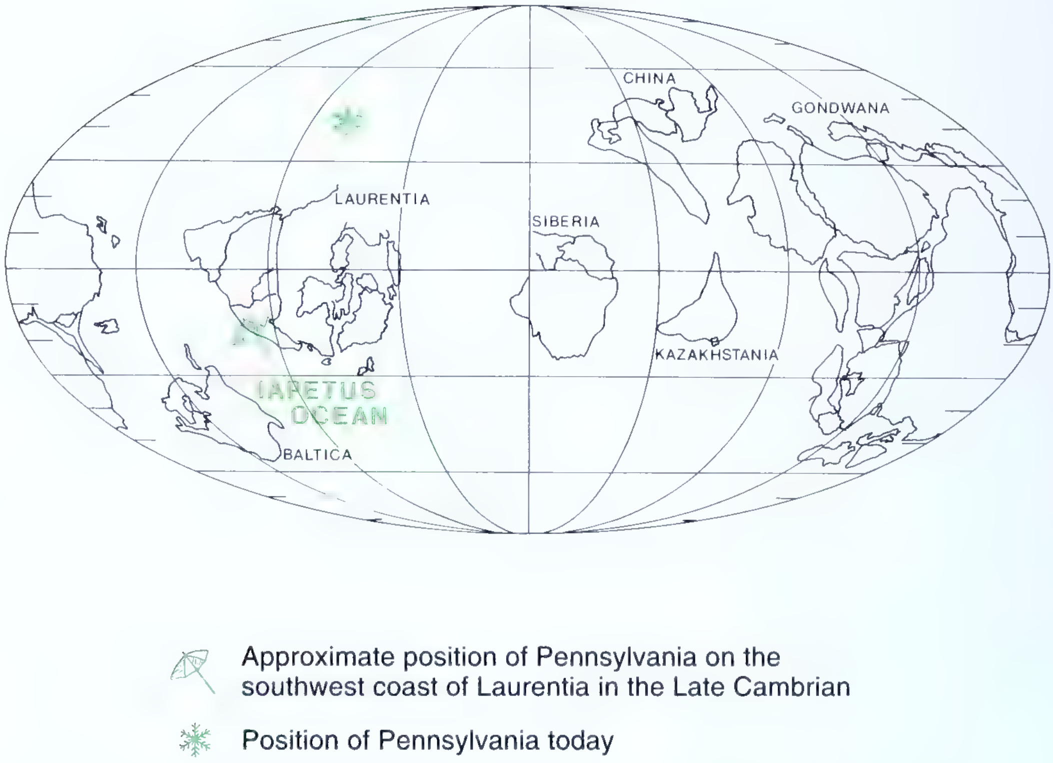
GROUNDWATER-RESOURCE MAPPING



GLOBAL GEOGRAPHY IN THE LATE CAMBRIAN

(modified from Bambach and others, 1980)

(see article on page 10)


CHINA
GONDWANA
LAURENTIA
SIBERIA
KAZAKHSTANIA
IAPETUS OCEAN
BALTICA
Approximate position of Pennsylvania on the southwest coast of Laurentia in the Late Cambrian
Position of Pennsylvania today

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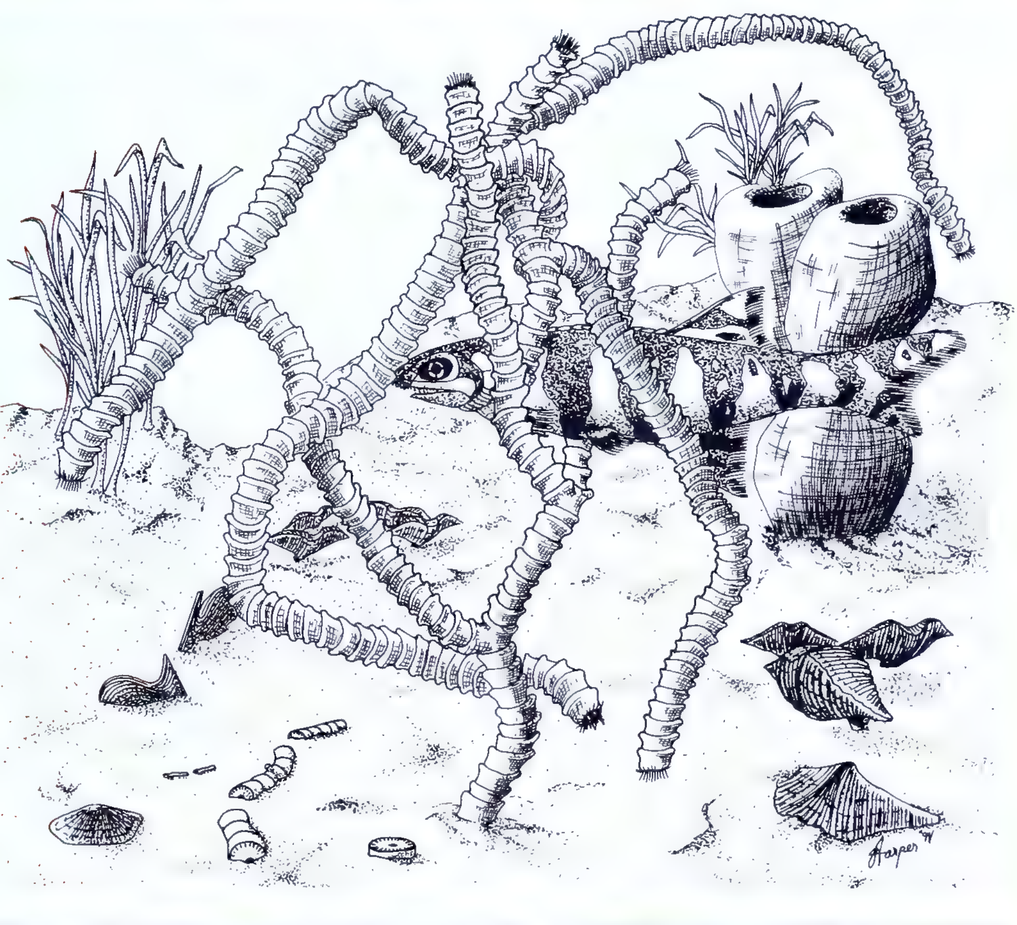

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL RESOURCES
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In memoriam—Louis Heyman, 1923–1994 15

ON THE COVER

Interpreted reconstruction of a portion of the Late Devonian Corry seafloor in the vicinity of what is now Titusville, Pa. (see article on page 2). A fine specimen of *Titusvillia drakei* Caster grows in the foreground, offering insubstantial shelter to a small paleoniscoid fish. To the right is a small group of *Cyrtospirifer* brachiopods, and some sponges and seaweed are present behind them. The brachiopod *Syringothyris,* the clam *Leiopteria,* and some seaweed grow in the left background. In the foreground is some scattered crinoid and brachiopod debris. Drawing by John A. Harper; *Titusvillia* based on Caster (1939, description and Figures 3 and 8).

PENNSYLVANIA GEOLOGY

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VOL. 25, NO. 3 **FALL 1994**

STATE GEOLOGIST'S EDITORIAL

Research in Geoscience

A recent newsletter *(American Paleontologist)* stated that geoscientists (specifically the newsletter readers, who are principally paleontologists) now need to focus their research proposals on "strategic" issues in order to receive funding support. "Strategic" research, a current defining buzzword, is explained as research that "advances the national social or economic well-being." Labeling research as "strategic" seems to impart some higher level of value than calling the research "basic," "core," "framework," or any of the many other labels that might be used to categorize a research proposal.

To be concerned about labeling research as strategic is, I believe, to participate in a subterfuge which avoids defining the values of research. All research that serves to better explain our world to us and allows us to become concordant with our world is supportable. The present-day trend of directing research to strategic issues, I believe, results from a long-standing and continuing reluctance of geologists and other scientists to acknowledge the need to adequately explain to their audiences, and to the larger public, the value and need for the research. Some scientists fear that they cannot be understood because of the inherent complexities of the science. However, science can be clearly explained to nonscientists, as many well-known scientists have proven. Some scientists disdain clear-language justifications as "popularizing" science. If it is beneath the dignity of a scientist to adequately explain the value of research in clear language, the research probably should not be supported.

From the notice included on page 12 of this issue of *Pennsylvania Geology,* you will learn about a report that includes extended descriptions of each of the investigations now being conducted by Pennsylvania Geological Survey staff. These projects are designed to explain Pennsylvania's geology and resources. Each was selected for investigation to provide a public service. I urge that you obtain this report, read about these investigations, and evaluate whether we have described each in a manner such that you can decide whether it has value and deserves your support. If you are not satisfied with the value of our research to yourself or to our Commonwealth through the provided descriptions, at your request we will respond to your concerns and provide further explanation.

Donald M. Hoskins

Donald M. Hoskins
State Geologist

Historical Marker Commemorates a Sponge, a Scientist, and the Oil Industry

by John A. Harper and Kathy J. Flaherty
Pennsylvania Geological Survey

How often have you seen or heard of a sponge being honored by a city, officials from local, state, and federal governments, the petroleum industry, a scientific research facility, and history buffs, all at the same time? In all likelihood, such an event had never occurred prior to August 27, 1993, when a new historical marker was unveiled on Union Street in Titusville, Pa. The plaque (Figure 1) commemorates the discovery and naming of an ancient fossil sponge found in the bed of Church Run in Titusville over 60 years ago.

Yes, a sponge! One of those lowly, primitive life-forms that consists of a semigelatinous blob held together by either a network of collagen fibers or a fairly rigid skeleton of siliceous or calcareous elements called spicules. A member of the phylum that you might have bought at the hardware store recently to wash your car or your bathroom walls.

Yet, as ridiculous as it might sound at first, the Devonian sponge *Titusvillia drakei* (Figure 2 and cover illustration) is unique and important enough to have been honored at the ceremony by the Titusville High School Marching Band, the pastor of St. Walburga Church, a member of the Titusville City Council, Titusville's "Man of the Year," representatives of the Pennsylvania and West Virginia Geological Surveys and the Bureau of Oil and Gas Management of the Pennsylvania Department of Environmental Resources, the Chief of the Paleontology and Stratigraphy Branch of the U.S. Geological Survey, the President of the Penn Grade Crude Oil Association, the Director of the Paleontological Research Institution in Ithaca, N.Y., the President of the Board of The Colonel, Inc., and a diverse audience of Crawford County and Venango County citizens. The attendance by so many people confirms the significance of the fossil. However, the marker and the event honored not just a sponge; included in the compliment were the scientist who found and identified it, the city of Titusville, the accomplishments of Colonel Edwin L. Drake, founder of the modern petroleum industry, and the petroleum industry itself.

THE MARKER. The hoopla surrounding the dedication of the historical marker took place at an annual event called Drake Day, in

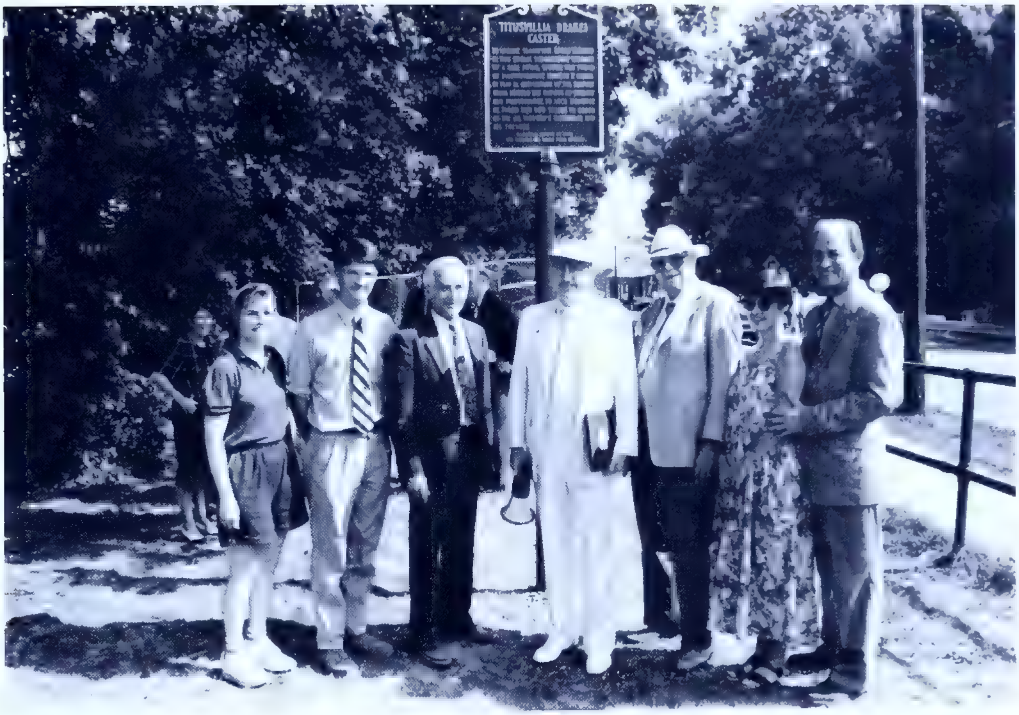

Figure 1. Some of the people present at the unveiling of the *Titusvillia* historical marker included, from left to right, Kathy J. Flaherty, Pennsylvania Geological Survey; Warren Allmon, Director of the Paleontological Research Institution in Ithaca, N. Y.; John Pojeta, Chief of the Paleontology and Stratigraphy Branch of the U.S. Geological Survey; Samuel T. Pees, President of the Board of The Colonel, Inc.; John H. Bryner, President of the Penn Grade Crude Association; Pat Johns, West Virginia Geological Survey; and Larry D. Woodfork, State Geologist of West Virginia. Photograph courtesy of Jim Farling, Quaker State Corporation.

honor of the day in 1859 when Colonel Edwin L. Drake's oil well finally "came in." The day typically consists of a variety of festivities, including live entertainment, a banquet, and a keynote address. The historical marker is the brainchild of Samuel T. Pees, a well-known consulting geologist and oil-field historian from Meadville, Crawford County. The placement and unveiling of the plaque were sponsored by The Colonel, Inc., a dynamic organization whose members help support exhibits, education, and preservation of oil-field history.

The dedication on the historical marker (Figure 1) reads, "In ancient sea bottom rocks exposed in this stream, the holotype specimen of a rare fossil sponge was found by paleontologist Kenneth E. Caster. In 1939 in recognition of the support which brought the sciences of geology and paleontology to such eminence he named this new species in honor of the oil industry's birthplace and its founder."

(A holotype is a specimen considered by the describer to be typical of the species, and to which all other specimens are to be compared.) In the paper in which he described the fossil, Caster (1939, p. 9) wrote, "The name *Titusvillia drakei* is given in recognition of the place of discovery of the holotype specimen and for the founder of the oil industry in Pennsylvania, without the ramifications of whose enterprise geology and paleontology could not have reached the station of eminence they hold today." Caster had created the name to honor the very dynamic interactions of the paleontological/geological community and the petroleum industry that has employed so many of its members over the past century. Many of the concepts that have shaped the science of geology as we know it today originated with oil-field geologists, paleontologists, geochemists, and geophysicists.

THE SPONGE. *Titusvillia drakei* is a member of the Hexactinellida, a class of sponges of highly variable shape that originated about 500 million years ago. These wholly marine animals are characterized by skeletons of six-pronged siliceous spicules. The glass sponge called "Venus's flower basket" is a good modern example of this class.

Unlike other hexactinellids, *Titusvillia* consisted of a branching supercolony of individual cuplike animals (cover illustration). Colonies (branches) diverged from a central axial colony at regular intervals in a spiral pattern. One especially interesting facet of this sponge was the tendency for some colonies to reverse the orientation of the cups—some are oriented outward from the axis, whereas others are oriented inward. Caster (1939, p. 8) speculated that this phenome-

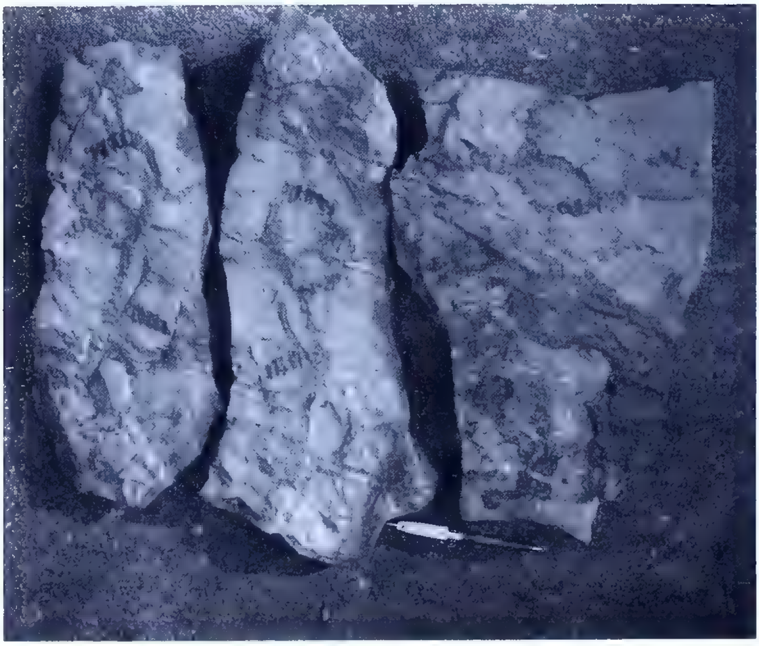

Figure 2. Three slabs of rock containing specimens of *Titusvillia drakei* Caster collected by Samuel T. Pees from an outcrop of Corry Sandstone at the Drake Well Museum. The pen at the bottom indicates the scale. Photograph courtesy of Samuel T. Pees.

non occurred when the supercolony became too massive for the skeleton to support all of the branches in a normal upright fashion. Then the branches drooped and the cups grew upward, that is, toward the axis, or horizontally along the seafloor. Collectors should be aware that a close look at a specimen with a hand lens or microscope may be required to see the network of spicules on the surface of the fossil.

Caster collected the type specimens of *Titusvillia drakei* in 1931, in the bed of Church Run about 50 yards north of the Union Street bridge over the creek. He included in his collections specimens from the areas around Johnsonburg in Elk County, Kushequa in McKean County, Pleasantville in Venango County, and Tidioute and Warren in Warren County. Another well-known locality is the outcrop of Corry Sandstone across the tracks from the railroad station at the Drake Well Museum (Hoskins and others, 1983). Caster thought that his specimens represented a strange form of fossil worm trail having unique nodes on it when he first found them. It was only when he began preparing a paper on Late Devonian trace fossils seven years later that he realized what he had discovered (Caster, 1939, p. 7).

THE SCIENTIST. Kenneth E. Caster (Figure 3) was a native Pennsylvanian, born in New Albany, Bradford County, in 1908. He spent a considerable part of his formative years in Ithaca, N.Y., where he developed an early interest in natural history. While studying for a bachelor's degree in zoology at Cornell University, which he received in 1929, he came under the influence of the eminent paleontologist Gilbert D. Harris (Holland, 1989). Among Harris' numerous contributions to the science of paleontology were the founding of the Paleontological Research Institution at Ithaca and its major publication series, the *Bulletins of American Paleontology,* considered one of the premier paleontological monograph series in the world. Caster helped Harris with the Institution collections, as well as with typesetting, preparing plates, and printing the Bulletins. This practical experience proved to be useful when he published his senior thesis on Late Devonian fossils from Pennsylvania and New York (Caster, 1930) as one of the Bulletins.

Caster's doctoral dissertation on the stratigraphy and paleontology of the Upper Devonian and Lower Mississippian of the New York-Pennsylvania border area also was published as one of the *Bulletins of American Paleontology* (Caster, 1934). It remains to this day one of the seminal publications dealing with Appalachian stratigraphy, particularly the facies concept.

Caster's descriptions and discussions of *Titusvillia* and other Devonian sponges are considered groundbreaking because the paper

Figure 3. Eminent paleontologist and stratigrapher Kenneth E. Caster, 1908–1992, with his wife and coresearcher, Anneliese (Annie). Photograph courtesy of David L. Meyer, University of Cincinnati.

was one of the earlier works that dealt with the biology and ecology of the organisms as well as their taxonomy and biostratigraphy. He is also credited with being one of the pioneers in the study of fossil animal tracks and trails (Holland and Pojeta, 1994).

Caster was interested in people as well as fossils. Considering the importance of science education, his influence on numerous amateur geologists and paleontologists in the Cincinnati area may have been his greatest contribution to society and the sciences. He was a helpful teacher and doting mentor to his many students. During his Drake Day keynote address, Dr. John Pojeta, Chief of the Paleontology and Stratigraphy Branch of the U.S. Geological Survey (Figure 1, third from left) and one of Caster's former students, spoke of Caster's keen sense of humor and his delight in his students' practical jokes. Pojeta cited as an example a birthday card full of confetti that fell onto Caster's lap, desk, and chair.

"Ken would have been delighted to know about today's *Titusvillia drakei* marker presentation," said Pojeta. "So, Ken, wherever you are, this marker's for you!"

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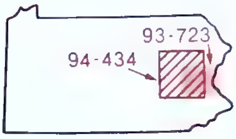
NEW PUBLICATIONS

New U.S. Geological Survey Open-File Reports



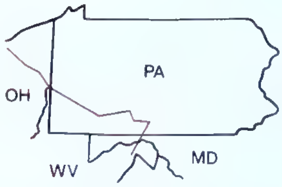
The U.S. Geological Survey (USGS) has issued two new open-file reports, both of which contain preliminary results of cooperative USGS-Pennsylvania Geological Survey geologic-mapping projects currently being funded under the National Geologic Mapping Act.

Open-File Report 93–723, **Surficial Geologic Map of Part of the Allentown 30´ x 60´ Quadrangle, Berks, Bucks, Carbon, Lehigh, Luzerne, Monroe, Northampton, and Schuylkill Counties, Pennsylvania,** by Duane D. Braun and Jack B. Epstein, consists of a 14-page text and an uncolored 1:100,000-scale regional surficial geologic map derived mainly from published 1:24,000-scale geologic maps. The text contains a map showing glacial borders as mapped by all previous workers and an explanation of the 22 surficial map units.

Open-File Report 94–434, **Late Wisconsinan to Pre-Illinoian (G?) Glacial Events in Eastern Pennsylvania,** by Duane D. Braun, Edward J. Ciolkosz, Jon D. Inners, and Jack B. Epstein, is the guidebook for the 57th Field Conference of the Northeastern Friends of the Pleistocene, held at Hazleton, Pa., on May 20–22, 1994. This 117-page report contains a detailed road log, descriptions of 15 localities illustrating glacial and periglacial processes in the North Branch Susquehanna Valley, Anthracite region, and Great Valley, and nine short articles on such subjects as bedrock geology, soil development, tors, and paleomagnetism.

Copies of these reports are available for inspection or loan from the library of the Pennsylvania Geological Survey, Evangelical Press Building, 1500 North Third Street, Harrisburg, or for purchase (Open-File Report 93–723 at $5.75 plus $0.35 state sales tax for Pennsylvania residents and Open-File Report 94–434 at $5.00 plus $0.30 state sales tax for Pennsylvania residents) from Jon D. Inners, Pennsylvania Geological Survey, P. O. Box 8453, Harrisburg, PA 17105–8453. Checks should be made payable to *Commonwealth of Pennsylvania.*

Stratigraphic Framework of Cambrian and Ordovician Rocks, Part 2



The U.S. Geological Survey (USGS) has published its fourth report in a series of restored stratigraphic cross sections showing the Cambrian and Ordovician rocks in the central Appalachian basin. The series includes two cross sections across Ohio and West Virginia and one across northeastern Ohio and northwestern Pennsylvania (Miscellaneous Investigations Series Map I–2200). The most recent report, Bulletin 1839–K, includes text and a cross section that extends from north-central Ohio across southwestern and south-central Pennsylvania into northeastern West Virginia. The cross section consists of the stratigraphic interval between the Lower Silurian and the Precambrian, and was compiled from geophysical and drill-hole data. The text contains a discussion of basement structures, the overlying stratigraphic intervals, and their interrelationships.

Appalachian basement structure beneath the Appalachian Plateaus province is only now being studied in any detail. At present, only a few wells have penetrated the sedimentary cover. Thus, we must rely on interpretation of mostly proprietary geophysical data such as seismic-reflection, aeromagnetic, and gravity surveys. The USGS authors use a combination of (a) the stratigraphic and structural variations in the Paleozoic sedimentary rock cover and (b) published seismic survey and gravity data to infer the basement structure along the lengths of the cross sections. The interpretations provided in these reports are provocative and should help stimulate some debate.

Bulletin 1839–K provides descriptions of the stratigraphic units from the basal Cambrian to the Lower Silurian Tuscarora Sandstone and its equivalents. The descriptions include thicknesses and basic compositions, lateral equivalents, synonyms, and discussions of pertinent previous and new research. For example, the reader will learn that the Beekmantown Group in Somerset County, Pa., is a 3,800-foot-thick dolomite interval traditionally considered to be of Early and Middle Ordovician age. However, conodont fossils recovered from drill cuttings indicate, questionably, that most of this sequence, the upper 3,000 feet, is of Middle Ordovician age. The authors believe that this age assignment for much of this sequence is incorrect, based on the supposition that fossils from higher in the bore hole might have contaminated the drill cuttings.

Bulletin 1839–K, **Stratigraphic Framework of Cambrian and Ordovician Rocks in the Central Appalachian Basin from Medina County, Ohio, through Southwestern and South-Central Pennsylvania to Hampshire County, West Virginia,** by R. T. Ryder, A. G. Harris, and J. E. Repetski, is available from the U.S. Geological Survey, Map Distribution, Federal Center, P. O. Box 25286, Denver, CO 80225, for $5.00 plus $1.00 for handling. Payment must accompany the order. Please make checks payable to *Department of the Interior—USGS.*

Sinkholes and Karst-Related Features of Chester, Montgomery, and Bucks Counties

Three new open-file reports have recently been released by the Pennsylvania Geological Survey. **Sinkholes and Karst-Related Features of Chester County, Pennsylvania** (Open-File Report 93–01), **Sinkholes and Karst-Related Features of Montgomery County, Pennsylvania** (Open-File Report 93–02), and **Sinkholes and Karst-Related Features of Bucks County, Pennsylvania** (Open-File Report 93–03) are part of a series of county-based reports that relate to sinkhole occurrences in Pennsylvania (see back cover). Compiled by staff geologist William E. Kochanov, each report includes a brief explanatory text and copies of 7.5-minute-quadrangle maps (1:24,000 scale). The methods used in compiling the report are described in the text, which also includes references and a glossary. The maps show the locations of karst surface depressions, sinkholes, surface mines, cave entrances, and carbonate bedrock geology.

The three reports may be examined at the Pennsylvania Geological Survey, Evangelical Press Building, 1500 North Third Street, Harrisburg. Copies of the reports may be purchased by mail from the Pennsylvania Geological Survey, P. O. Box 8453, Harrisburg, PA 17105–8453. The prepaid copying and shipping costs are as follows: Chester County report, $25.00 plus $1.50 state sales tax for Pennsylvania residents; Montgomery County report, $15.00 plus $0.90 state sales tax for Pennsylvania residents; and Bucks County report, $12.50 plus $0.75 state sales tax for Pennsylvania residents. Please make checks payable to *Commonwealth of Pennsylvania.*

Plain English Booklet Explains Aggregate Business

Aggregate is one of the most commonly used mineral commodities in the United States, yet it is also one of the least understood and most taken for granted. "Aggregate" is the name applied to all the sand, gravel, crushed stone, and similar materials that are used for the construction of highways, bridges, dams, tunnels, and most other major and minor structures. Between 1970 and 1990, an average of 1.84 billion tons of aggregate was used in the United States every year. Even the construction of a typical six-room house requires 90 tons of aggregate.

In order to increase public awareness and understanding of the aggregate industry, the U.S. Geological Survey has issued a colorful publication, written in plain English for the nongeologist, entitled **Natural Aggregate—Building America's Future.** The authors, William H. Langer and V. M. Glanzman, describe all aspects of this major mineral commodity, the production of which yielded a gross value of about $9.1 billion in the United States in 1990. A portion of the booklet is devoted to a discussion of the uses of aggregate and the types of materials that are used for aggregate in various parts of the United States. Most of the remainder is devoted to a discussion of the many factors that determine where and how aggregate is mined. Among these are the demand for aggregate for a particular purpose in a given area versus the availability of aggregate having appropriate properties for that use in that area, the cost of transportation from a distant site versus the cost of land acquisition and development at a site closer to the place where the aggregate is needed, and the reconciliation of conflicts between the producers of aggregate and the people who must coexist with an aggregate-extraction facility nearby.

Natural Aggregate—Building America's Future should be a useful source of background information for local officials who must make informed decisions regarding the enactment of regulations controlling zoning, land use, traffic, and noise that affect the aggregate industry. Property owners who are affected by such decisions might also find this booklet a useful source of information in understanding this important industry. This full-color 39-page booklet, U.S. Geological Survey

Circular 1110, is available free on request from the U.S. Geological Survey, Map Distribution, Box 25286, Building 810, Denver Federal Center, Denver, CO 80225.

Report Issued on Potential New Natural Gas Reservoir

Pennsylvania Geological Survey geologists participated with geologists of the Ohio Geological Survey in producing timely geological information on an active hydrocarbon target in western Pennsylvania and eastern Ohio. John A. Harper, Chief of the Subsurface Geology Section, and Christopher D. Laughrey, Geologist in the Section, were part of a five-member interstate team who, within a two-year period, studied the hydrocarbon potential of the Cambrian-age Rose Run Sandstone of western Pennsylvania and eastern Ohio, and compiled and published a geologic report. This formation is currently the most active exploration target in the Appalachian basin. The team described and interpreted the numerous geological factors affecting the variability of the Rose Run Sandstone (Upper Sandy Member of the Gatesburg Formation). In Pennsylvania, this potential hydrocarbon reservoir is encountered at a minimum of approximately 1 mile below the surface in Erie County and at a maximum of more than 3 miles below the surface in Somerset County. Four distinct types of hydrocarbon trapping mechanisms were identified for this single reservoir.

Measuring and Predicting Reservoir Heterogeneity in Complex Deposystems: the Late Cambrian Rose Run Sandstone of Eastern Ohio and Western Pennsylvania is a 257-page report that was prepared for the U.S. Department of Energy by the Appalachian Oil and Natural Gas Research Consortium of which the Pennsylvania Geological Survey is a member. The book is available for $10.00 plus $2.00 for postage and handling from the Pittsburgh Geological Society, P. O. Box 3432, Pittsburgh, PA 15230. It is also available from the Ohio Department of Natural Resources, Division of Geologic Survey, 4383 Fountain Square, Columbus, OH 43224–1362, telephone 614–447–1918.

Geological Research in Pennsylvania, 1993–94

The Pennsylvania Geological Survey recently released **Geological Research in Pennsylvania, 1993–94,** a 53-page compilation of geological research in Pennsylvania reported for the period 1993 through the first half of 1994. A listing of geological reports published during the same time period is also included. For a free copy of the report, contact the Pennsylvania Geological Survey, P. O. Box 8453, Harrisburg, PA 17105–8453, telephone 717–787–2169.

ANNOUNCEMENTS

Mineral Collecting in Pennsylvania (G 33) Now Out of Print

The fourth edition of *Mineral Collecting in Pennsylvania* (General Geology Report 33), which consisted primarily of brief descriptions of some prominent mineral-collecting localities in the state, is now out of print and will not be reprinted in its present format. This is partly because at least one third of the sites are no longer open for collecting. Also, it is no longer easy to obtain permission from property owners to include their properties in such a list.

Collectors looking for interesting localities may wish to contact local mineral clubs, which could provide information. A list of mineral clubs in Pennsylvania is available from Richard Keen, Librarian, Pennsylvania Geological Survey, P. O. Box 8453, Harrisburg, PA 17105–8453.

If a new format that reflects the realities of mineral collecting in the 1990's can be designed, a new edition of this handbook may be printed. Your suggestions regarding the content or style of a new edition are welcome and requested, and may be sent to the Director of the Pennsylvania Geological Survey at the address listed in the preceding paragraph.

Other Survey publications that may be of interest to some mineral collectors include the following: ES 1, *Rocks and Minerals of Pennsylvania* (free); IC 54, *Directory of the Nonfuel-Mineral Producers in Pennsylvania* ($6.00); M 27, *Manganese Minerals of Pennsylvania* ($3.40); M 43, *Uranium in Pennsylvania* ($2.50); M 50, *Atlas of Pennsylvania's Mineral Resources—Part 3, Metal Mines and Occurrences in Pennsylvania* ($3.50); M 72, *Zinc and Lead Occurrences in Pennsylvania* ($14.55); M 78, *Mineralogy Associated With Burning Anthracite Deposits of Eastern Pennsylvania* ($3.65); and M 80, *Geology and Mineralogy of Copper-Uranium Occurrences in the Picture Rocks and Sonestown Quadrangles, Lycoming and Sullivan Counties, Pennsylvania* ($19.00). Some of these reports include specific localities where minerals may be found. ES 1 can be obtained by contacting the Pennsylvania Geological Survey, P. O. Box 8453, Harrisburg, PA 17105–8453; telephone 717–787–2169. The other publications are available at the cost indicated, plus 6 percent state sales tax if mailed to a Pennsylvania address, from Department of General Services, State Book Store, 1825 Stanley Drive, Harrisburg, PA 17103–1257. Checks should be made payable to *Commonwealth of Pennsylvania.*

Mineral Producer Directory to be Updated

by John H. Barnes
Pennsylvania Geological Survey

The fourth edition of the Pennsylvania Geological Survey's Information Circular 54, **Directory of Nonfuel-Mineral Producers in Pennsylvania,** was published in 1985 and is among the Survey's better selling publications. The purpose of this directory is to assist the large nonfuel-mineral industry in Pennsylvania by helping producers and consumers of mineral commodities locate each other. In late 1994, we began what we anticipate will be a two-year effort to compile data for a new edition that will reflect changes in the industry over the past 10 years.

Production statistics prove the importance of the nonfuel-mineral industry to Pennsylvania. In the late 1980's, production reached a peak of over $1 billion. In 1992, the most recent year for which statistics from the U.S. Bureau of Mines are available, the value of production in Pennsylvania was approximately $863 million. Pennsylvania ranked first in the nation in stone production in 1992, fourth in the production of cement, third in the production of lime, eleventh in the production of clay, thirteenth in the production of sand and gravel, and thirteenth in the total value of all nonfuel-mineral production. This level of production is equivalent to 540 pounds of minerals every week for each of the state's 11.9 million citizens.

The content of the fifth edition of the directory will be similar to that of the fourth. The name, address, location, telephone number, and type of each operation will be listed, as will the geologic resource being mined or quarried, the normal uses of the mined material, and other information that pertains to the operation. As before, the location of each operation will be plotted on a 1:500,000-scale folded map.

Preparing a directory such as this is a cooperative effort between the Survey and the state's mineral industry. In the near future we will send questionnaires to the mineral producers who are listed in the fourth edition. Additional questionnaires will be sent to those not previously listed whom we are able to identify from industry and trade association records and from permit files. We hope that those who receive them will provide the cooperation that we have enjoyed in the past so that the listings in the new directory will be as complete and accurate as possible.

EARTH SCIENCE TEACHERS' CORNER

Video Brings Mining into the Classroom and Stimulates Discussion

by John H. Barnes
Pennsylvania Geological Survey

Few of us take the time to notice where the things that we encounter every day really come from, but if we did we would find that nearly everything we see, hear, and touch came from mining. This is one of the points raised by an interesting, well-paced 10-minute video produced by the American Mining Congress entitled **Mining: Discoveries for Progress.** Among the interesting facts presented are the following:

- —In the United States, 40,000 pounds of minerals are used per person per year.
- —Nearly 300,000 people are employed by the mining industry.
- —Mining is responsible for the indirect employment of more than 3 million people.
- —Mining accounts for exports of as much as $6 billion per year.
- —Laws now protect air, water, vegetation, and historic sites from mining activities.
- —Modern reclamation techniques can restore mined land to other uses.
- —Minerals are where you find them. We do not have the luxury of finding minerals where we would like them to be.

Mining is portrayed in this video as a modern high-tech industry that provides safe, high-paying jobs for men and women across the country in many professions, among them environmental science, engineering, manufacturing, accounting, biology, and geology. Although this portrayal is, to some degree, true, it must be kept in mind that the video was produced by an organization that is an advocate of mining interests. The bias of this organization becomes most apparent near the end of the video, when a case is made that more Federal lands should be opened to mining development. This bias could, however, serve as a catalyst for interesting classroom discussion after the video has been viewed.

Mining: Discoveries for Progress is being distributed by the American Mining Congress to schools, civic groups, and mining associations, as well as television stations. Copies are also for sale at $10 each, $7.50 each for 50 to 99 copies, and $6.00 each for 100 copies or more. For more information, write to the American Mining Congress, 1920 N Street NW, Suite 300, Washington, DC 20036–1662, telephone 202–861–2800.

IN MEMORIAM

Louis Heyman

1923–1994

1966–1979 Pennsylvania Geological Survey

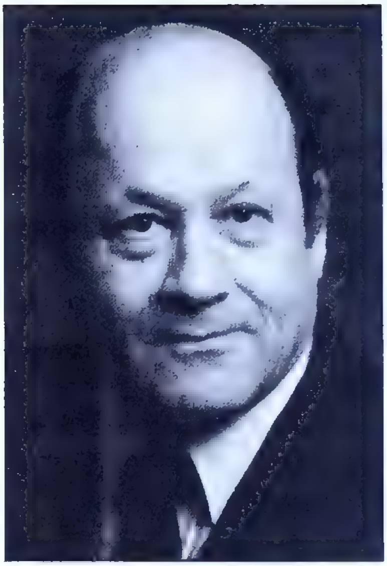
Louis Heyman, a geologist who worked in the Survey's Pittsburgh office for 13 years, died in Amarillo, Tex., on February 10, 1994, just 15 days before his 71st birthday.

Lou was born and reared in the Bronx, N. Y., the younger of two children. He began college in 1941, but his formal education was interrupted by World War II.

After serving in the South Pacific, Lou returned to school and received a B.S. degree in geology from Brooklyn College in 1947 and an M.S. degree in geology from the University of Michigan in 1949.

Lou worked as a geologist for Kerr-McGee Oil Industries and Continental Oil Company in Amarillo and Oklahoma City until 1963, when he began working on a Ph.D. degree at Virginia Polytechnic Institute in Blacksburg, Va. He joined the Pennsylvania Geological Survey in 1966 and in 1970 received his degree upon completion of his dissertation on *Petrology of the Basal Middle Ordovician Blackford Formation of the Type Belt, Russell County, Virginia*.

While he was with the Survey, Lou worked on a variety of projects ranging from resource evaluation to environmental geology, most of which resulted in published reports. Perhaps his best known contributions are Mineral Resource Report 59, *Geology of the Elk Run Gas Pool, Jefferson County, Pennsylvania,* and Mineral Resource Report 73, *Tully (Middle Devonian) to Queenston (Upper Ordovician) Correlations in the Subsurface of Western Pennsylvania.* Lou also contributed to General Geology Report 59, *Geology of the Pittsburgh Area,* and coauthored a variety of maps for the Pittsburgh Regional Environmental Geologic Study (PREGS). He was working on his magnum opus, a regional study of the Lower Devonian Oriskany Sandstone, when he left in 1979 to return to the oil industry. Lou worked for Coastal Corporation as an exploration geologist in its Amarillo office until 1984, and spent the remainder of his life as a consultant specializing in the geology of the Texas panhandle.



Photograph from AAPG Bulletin, v. 78, no. 7, p. 1098. Reprinted by permission.

Louis Heyman truly was a unique individual, and his years with the Survey were memorable in many respects. He was brilliant, extremely well read, and had a highly retentive memory that allowed him to carry on an intelligent conversation on almost any subject. He often would go out of his way to help a visitor or a fellow Survey staff member solve a geologic problem.

Lou is survived by a brother, a daughter, two sons, and a grandson. His wife, Sarah McConnell Heyman, died several years ago.

—John A. Harper

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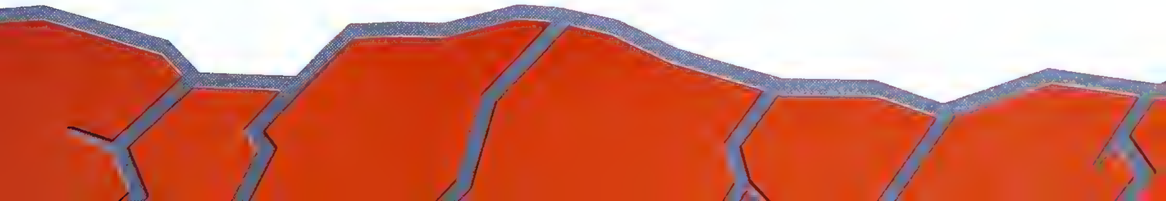
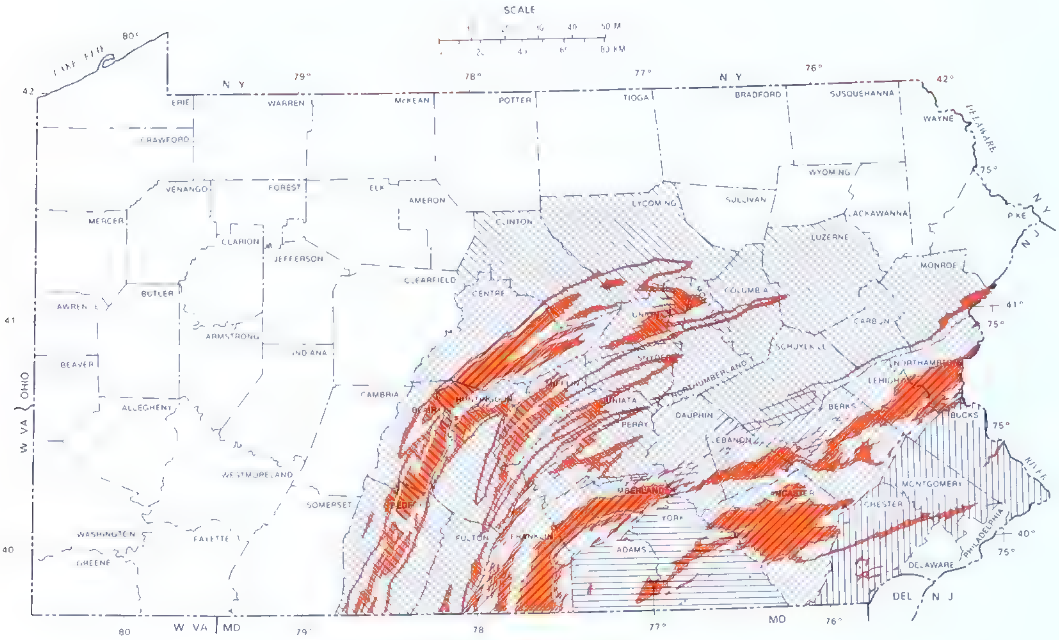
IN COOPERATION WITH THE U.S. GEOLOGICAL SURVEY

TOPOGRAPHIC MAPPING
GROUNDWATER-RESOURCE MAPPING



STATUS OF SINKHOLE-INVENTORY COUNTY REPORTS

(see article on page 9)



EXPLANATION

▥ Newly completed reports (see page 9)

▤ Counties where work is in progress

▨ Previously completed reports

▧ Counties remaining to be studied

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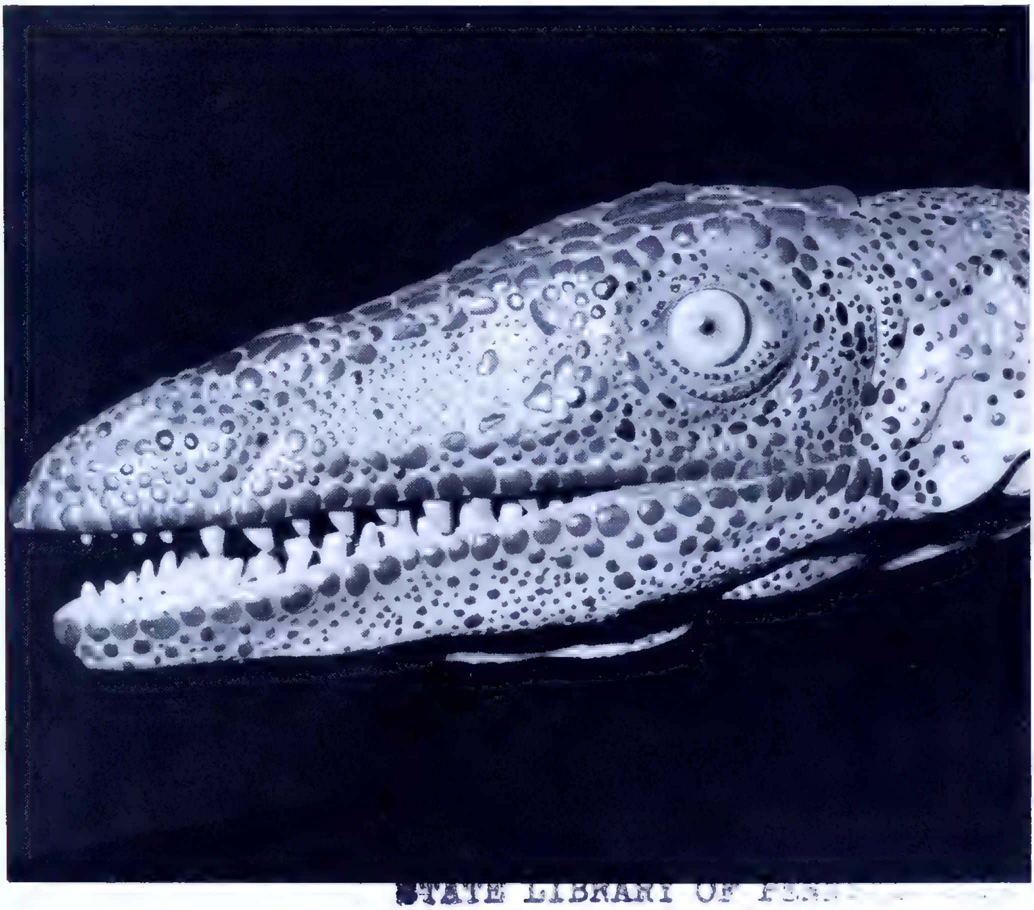

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ON THE COVER

Rioarribasaurus, formerly *Coelophysis,* a small bipedal dinosaur that probably roamed through Pennsylvania during the Late Triassic (see article on page 2). Photograph by Claire Messimer.

PENNSYLVANIA GEOLOGY

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STATE GEOLOGIST'S EDITORIAL

Near-Surface Geology—Critical to Modern Land Management Decisions

In H. G. Wells' early twentieth century fantasy novel of a trip to the moon, the reaction of moon people to the fact that earth dwellers did not know very much about the interior of their own planet was astonishment. Unfortunately, if these imaginary moon dwellers were to make contact with earth today, nearly a century later, they would be similarly astonished. For the truth is that we have limited information about the details of the near-surface geology of our earth, our nation, and our state. Perhaps it is for this reason that the nationally respected U.S. Geological Survey (USGS) is now being challenged for its lack of focus on modern geologic and topographic information applicable to human needs. Current U.S. congressional initiatives recommend abolishing or significantly reducing the USGS, U.S. Bureau of Mines, and other federal agencies that provide earth-resource information. An article on these initiatives was published in the January 1995 issue of *Geotimes,* the journal of the American Geological Institute. A copy of this article may be obtained by calling or writing to me.

The Association of American State Geologists, representing the state geological surveys, noted recently that only about 25 percent of our nation's land surface has been geologically mapped at a detail sufficient to meet modern information needs. In Pennsylvania, bedrock reconnaissance geologic information is available for of all of the state, but the same is not true for the extensive surficial geological materials that in most areas cover the bedrock. Addressing the surficial as well as more detailed bedrock information gaps is now the primary objective of our Pennsylvania Survey.

The task of state and federal geological surveys is to map the earth's surface and to investigate and explain the interior of our planet. By focusing on information on near-surface geological materials and processes, difficult management decisions can be made that will allow use of the earth's surface, as well as its interior, in a manner that contributes to human well-being. In my opinion, removing a credible source of such information, whose value constantly increases as we develop and use more of the earth's surface, through abolishment of the federal geologic and topographic survey, would not be in the best interest of our nation.

Donald M. Hoskins

Donald M. Hoskins
State Geologist

THE GRATERFORD DINOSAURS:
Tracking Triassic Travelers

by Robert M. Sullivan, Kesler Randall, and Michael Hendricks,
The State Museum of Pennsylvania; and William E. Kochanov,
Pennsylvania Geological Survey

Paleontologists are often asked to identify a "dinosaur bone," "dinosaur egg," or "dinosaur track." More often than not, these turn out to be nothing more than a soup bone, concretion, or some nondescript sedimentary structure, much to the chagrin of the proud discoverer. On rare occasions, these finds are scientifically significant. Such is the case with the recent discovery of dinosaur footprints at the State Correctional Institution at Graterford, Pa.

DISCOVERY. Late in 1993, inmate Wayne Covington, an amateur archaeologist and paleontologist, accidentally discovered footprints in an outcrop of the Late Triassic Lockatong Formation, which was exposed in a ravine on prison property. Personnel at The State Museum of Pennsylvania were notified of the discovery, and together with a geologist from the Pennsylvania Geological Survey, they conducted a joint field trip to assess the site.

The Graterford site consists of several rock layers that crop out in two ravines. The surfaces of these rock layers occur within a 2-meter (7-ft) sequence and contain scattered fossil footprints of various sizes. These are trace fossils, or ichnites (from the Greek *ichno,* meaning trace or track). The footprints are oriented in various directions, and some trace the path of a single individual. A few of the footprints are superimposed on preserved mudcracks and ripple marks. The myriad of footprints, and the extent of the locality, make it the largest dinosaur trackway site ever discovered in Pennsylvania.

Two large trackway horizons were uncovered and removed for study and conservation. The largest measured over 6 m (20 ft) long and 3 m (10 ft) wide. Prior to removal, a grid system was outlined on the bedding surface using natural subparallel fractures as a guide. In order to preserve the integrity of the trackway, each grid unit was sequentially numbered so that the trackway could be easily reassembled back in the museum laboratory. The sections, measuring approximately 1 m (3 ft) square and 10 to 15 cm (4 to 6 in.) deep, were cut using a portable rock saw (Figure 1). Crowbars were then used to pry up and remove the trackway sections.

HISTORY. The occurrence of dinosaur footprints in eastern North America is not new or uncommon. The first historical account of fossil footprints is credited to a young boy named Pliny Moody, who discovered a series of footprints in 1802 while plowing a field in the Connecticut River valley (Hitchcock, 1858).

When the young Moody stumbled upon these tridactyl (three-toed) tracks, dinosaurs were completely unknown to humans. In fact, the first fossilized dinosaur remains (isolated teeth) were not discovered and described until 1822, by Gideon Mantell, and the comparative anatomist Sir Richard Owen did not coin the term "Dinosauria" (which means "terrible lizard") until 1841. The distinctive three-toed tracks, although much larger, were similar in shape to those made by modern-day birds.

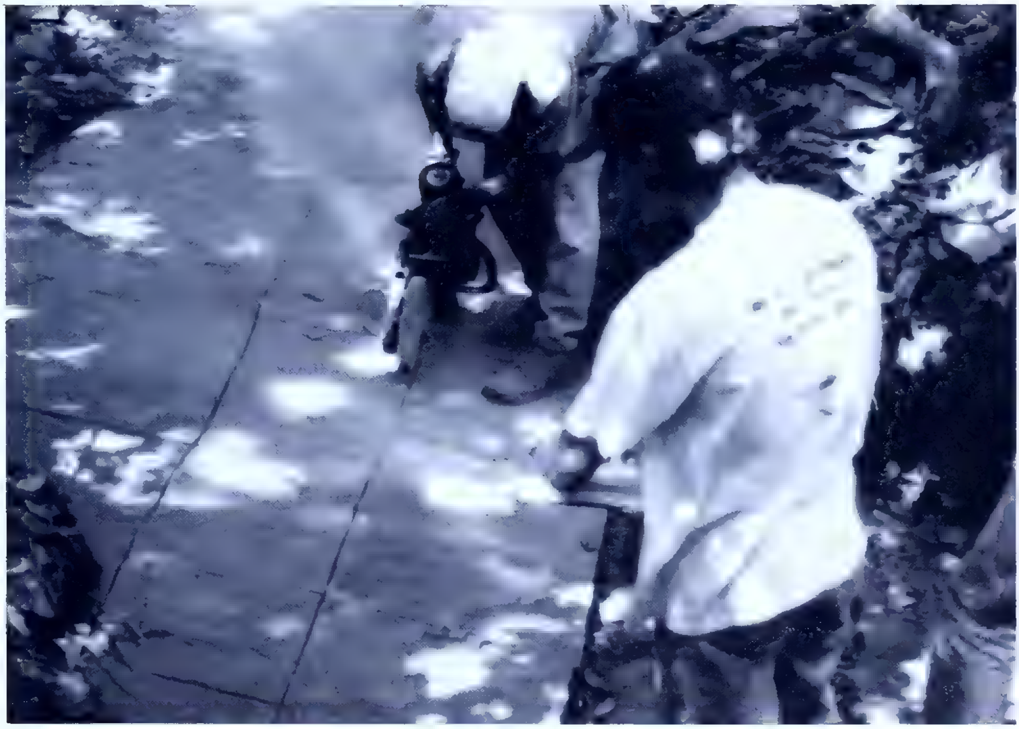

Figure 1. Using a cut-off saw, sections of the trackway were cut along a marked grid and were removed and taken to the museum to be studied.

Hence, they were considered by the common folk of the time to have been made by giant "poultry" or "Noah's Raven" (Hitchcock, 1858).

During the early and middle 1800's, thousands of Connecticut Valley footprints were discovered and became the subject of intense study by Rev. Edward Hitchcock, who published comprehensive accounts of these fossil tracks (Hitchcock, 1836, 1858, 1865). By the middle of the nineteenth century, over 21,000 footprints had been collected from various Connecticut Valley sites and were deposited in the Appleton Cabinet (now the Pratt Museum) of Amherst College in Amherst, Mass. (Hitchcock, 1865).

Hitchcock recognized that the footprints came from strata equivalent to the Liassic (Late Triassic) and Jurassic rocks of Europe and that these units occurred discontinuously in Massachusetts, Connecticut, New Jersey, Pennsylvania, Virginia, and North Carolina (Hitchcock, 1858). Hitchcock died not knowing that many of the footmarks he studied were made by prehistoric reptiles known today as dinosaurs.

For over a century, three-toed footprints were considered to have been made by dinosaurs that walked exclusively on their hind legs (obligatory bipedal dinosaurs). It was assumed that these dinosaurs walked solely on their hind legs because no manus prints (those made by the forelimbs) had been described in association with pes prints (those made by the hind limbs). Recently, Olsen and Baird (1986) reexamined a number of footprints from the Passaic and Lockatong Formations of the Jurassic-Triassic Newark Supergroup basins of New Jersey and Pennsylvania. They noted tridactyl manus impressions associated with some of the footprints and concluded that these tracks were made by a facultative quadrupedal dinosaur (one that occasionally got down on all fours), rather than a bipedal dinosaur. These prints, which were previously named *Gigandipus? (Anchisauripus) milfordensis* (Bock, 1952), were reclassified and put into a new ichnogenus, *Atreipus,* and were considered to have been made by an ornithischian ("bird-hipped") dinosaur rather than a saurischian ("lizard-hipped") dinosaur (Olsen and Baird, 1986).

The morphology of the manus prints associated with some of the *Atreipus* pes prints seems to exclude *Atreipus* from the dinosaur order Saurischia, because these manus prints are characterized (in part) by having well-developed tridactyl impressions of digits II, III, and IV rather than digits I, II, and III (see the sidebar at the top of the next page on "Fingers and Toes," and Figure 2) as would be expected with

FINGERS AND TOES. Paleontologists and biologists have devised a convenient way of referring to the fingers of the forelimb and the toes of the hind limb. Fingers and toes are called digits, and each digit is composed of bones referred to as phalanges (singular, phalanx). The proximal phalanx (the one closest to the body of the animal) articulates with a metacarpal (if in the forelimb) or metatarsal (if in the hind limb). The number of phalanges of each digit varies by digit and by species of animal (Figure 2). Digits are assigned Roman numerals. In the forelimb, digit I is the pollex (thumb); in the hind limb, digit I is the hallux (large toe in humans). The next digit (next to the thumb or large toe) is II, and so on.

Paleontologists have ascertained that the phalangeal formula for primitive reptiles is 2.3.4.5.3 (Romer, 1956). That is, there are 2 phalanges in the pollex, 3 phalanges in the next digit, and so on. In saurischian dinosaurs, digit II is the longest; in theropod dinosaurs, digit I of the forelimb is either absent or reduced, digit IV of the forelimb is reduced or absent, forelimb digit III has reduced (short) first and second phalanges, and digit IV of the hind limb is reduced. The ornithischian dinosaurs are in part characterized by a reduced digit V composed solely of a small metatarsal (no phalanx) (Benton, 1990).

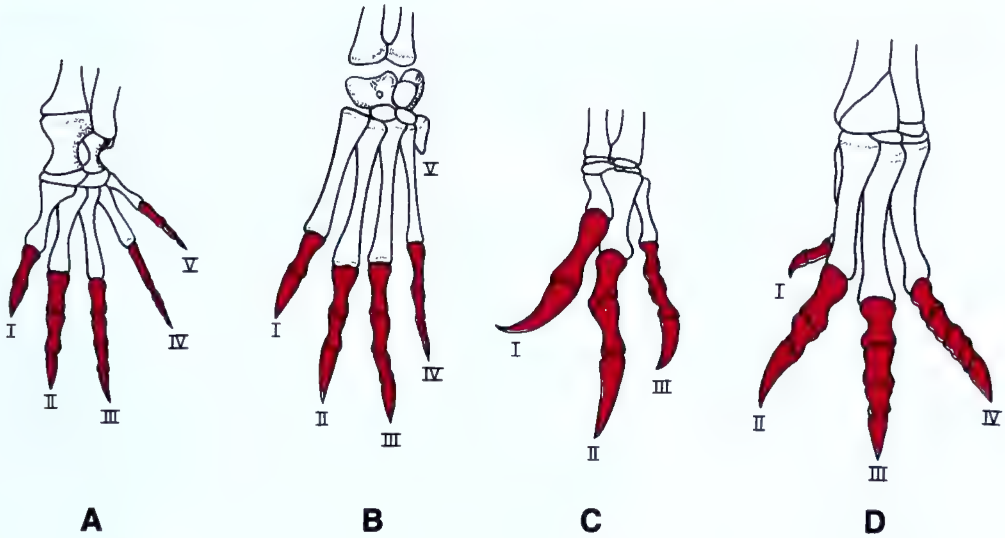

Figure 2. Manus (forelimb) and pes (hind limb) of the crocodile *Crocodylus* (A and B) and the theropod dinosaur *Allosaurus (Antrodemus)* (C and D) showing digits and phalangeal formulas (colored phalanges). (After A. S. Romer, *Osteology of the Reptiles*, University of Chicago Press. © 1956 by the University of Chicago. All rights reserved. Published 1956. Second impression 1968. Printed in the United States of America.)

theropod (advanced saurischian) dinosaurs (Olsen and Baird, 1986). However, there are other tridactyl pes prints that occur alone. Were these tracks made by a two-legged or a four-legged beast?

Surprisingly, the evidence is inconclusive for two reasons. First, the taxonomy of tridactyl footprints is confusing because a plethora of names has been given to the various similar prints. Second, the relationships of footprints to each other, and to the animals that made them, is far from certain.

Four ichnospecies of *Atreipus* are recognized in eastern North America (Olsen and Baird, 1986) and are similar to those named *Grallator* and *Anchisauripus,* which have been considered to be members of different ichnofamilies! *Grallator*-like footprints, and those currently called *Grallator (Grallator)* and *Grallator (Anchisauripus),* are still considered to have been made by Late Triassic obligatory bipeds like the well-known saurischian dinosaur *Rioarribasaurus* (=*Coelophysis)* (Lockley, 1991). Twelve ichnogenera have been recognized in the sedimentary rocks of the Newark basin, seven of which have been reported as occurring in the Lockatong Formation (Silvestri and Szajna, 1993).

THE GRATERFORD TRACKWAYS. At the Graterford site, three, or possibly four, distinct footprints have been uncovered, three of which can be attributed to dinosaurs. The smallest prints, which are nondinosaurian, measure no more than 2 cm (0.8 in.) in length. They are pentadactyl (five-fingered) in form and pertain to "lizard-like" footprints called *Gwyneddichnium* or *Rhynchosauroides* (not figured). The largest of the dinosaur pes prints, some of which are associated with tridactyl manus impressions, are considered *Atreipus milfordensis* and measure 15 cm (6 in.) in length (Figure 3). A few of these large prints are not associated with manus impressions and may belong to another ichnogenus called *Grallator (Anchisauripus).* Owing to variations in preservation, these prints may have, in

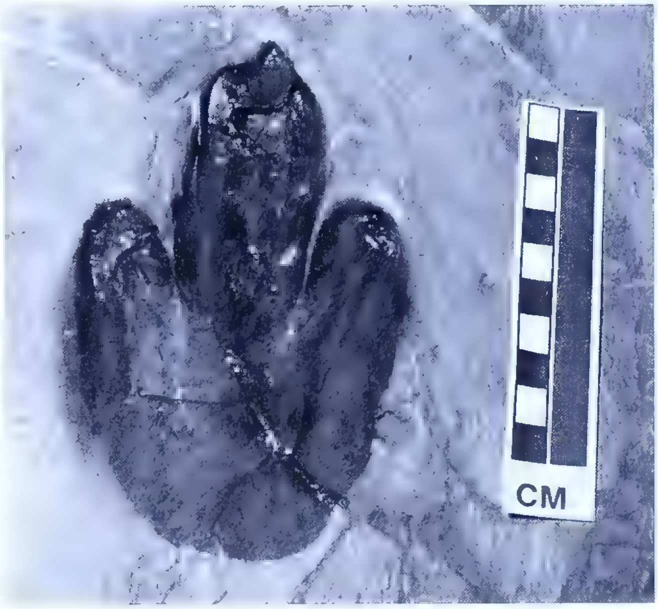

Figure 3. A pes print of the ichnotaxon *Atreipus milfordensis* from the Graterford site.

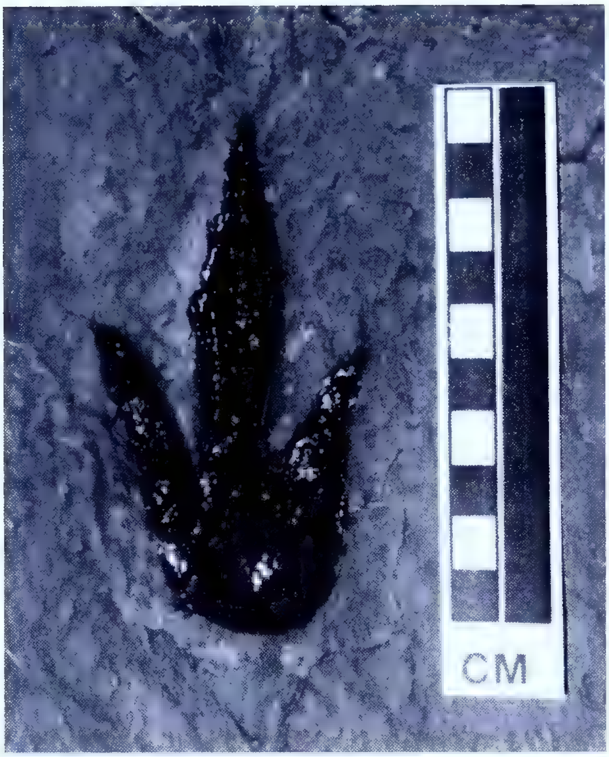

Figure 4. A pes print of the ichnotaxon *Coelosaurichnus* sp. from the Graterford site. Its occurrence in the Lockatong Formation extends the biostratigraphic range of the footprint earlier in time.

fact, been made by dinosaurs within the same taxon.

Of particular significance is the occurrence of the tridactyl dinosaur footprint referable to *Coelosaurichnus.* These pes prints measure 9 to 9.5 cm (3.5 to 3.7 in.) in length and have an elongated middle toe (digit III) with a digit divarication (angle formed between two digits) of 28 degrees (Figure 4). If our identification of these prints is correct, this is the first occurrence of this ichnotaxon in the Lockatong Formation and is the oldest known occurrence of this footprint in the Newark Supergroup, based on data provided by Silvestri and Szajna (1993).

TRAVELING THE TRIASSIC TURNPIKE. What dinosaurs made these tridactyl footprints? We know that three-toed dinosaurs roamed between what is now the United States, Great Britain, and South Africa before the supercontinent of Pangaea began to break up some 220 million years ago. The skeletal remains of two relatively small and very closely related ceratosaur dinosaurs have been found on the continents of North America, Europe, and Africa. The saurischian dinosaur *Rioarribasaurus* is known from Late Triassic sediments of the southwestern United States. *Syntarsus* has been discovered in Late Triassic rocks of England and Rhodesia (Zimbabwe). It is also known from the Early Jurassic Kayenta Formation of Arizona and now appears to be present in the Late Triassic Rock Point Formation (Chinle Group) of New Mexico (Sullivan, in preparation). These dinosaurs

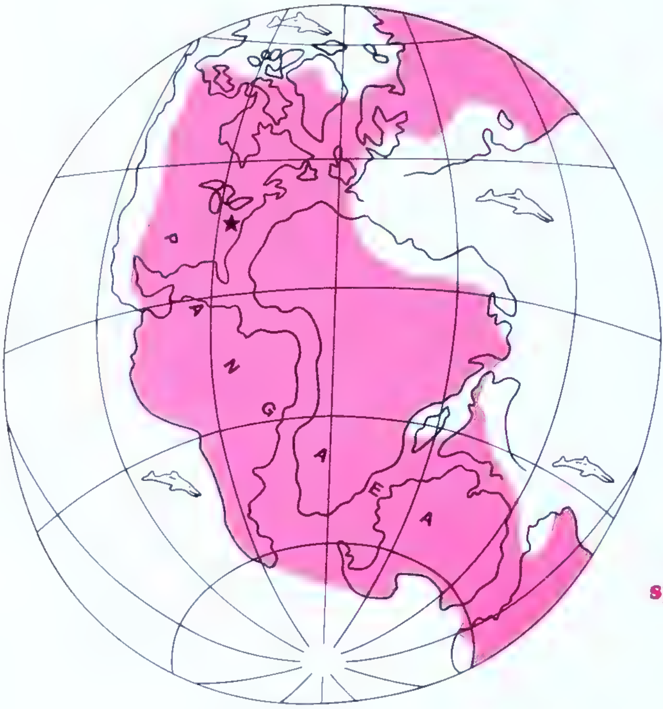

Figure 5. Pangaea during the Late Triassic. North America, Europe, and Africa were together, allowing for faunal interchange to occur between these geographic regions. (Modified from Spencer G. Lucas, *Dinosaurs: The Textbook*. Copyright © 1994 Wm. C. Brown Communications, Inc., Dubuque, Iowa. All rights reserved. Reprinted by special permission.)

are believed to be responsible for some of these tracks (see cover photograph).

The interchange of vertebrate life between these distant places was certainly not an uncommon event. During the Late Triassic, Pennsylvania, the southwestern United States, and Europe were all situated near the equator (Figure 5). As in the present, southern Africa was then geographically distant, yet land connected these vastly separated regions, allowing for faunal dispersal. Perhaps these dinosaurs wandered along the equatorial corridor, leaving their footprints in Pennsylvania. They continued to do so until the vast rift that ultimately became the Atlantic Ocean prevented their wanderings.

The discovery at Graterford provides new information concerning vertebrate life during the Late Triassic of Pennsylvania. Except for the discovery of a couple of ornithischian dinosaur teeth a hundred years ago (Hunt and Lucas, 1994), and isolated footprints occasionally observed in our state, direct evidence of dinosaur life has been conspicuously absent. The search continues for skeletal remains of the elusive Pennsylvania dinosaur.

We thank Wayne "Fang" Covington and Ahmed Sabur for preparing the trackway site and for their enthusiastic support and help in *this project. Thanks are extended to Robert Larkin, who brought the discovery to our attention; Superintendent Donald Vaughn, Deputy Superintendent Thomas Stachelek, and their staff at the State Correctional Institution, for allowing us to collect the Graterford footprints; and Dr. Hartmut Haubold (Geiseltalmuseum, Halle, Germany) for his discussions and insight on ichnite identifications.*

NOTE: The Graterford locality continues to be an active research field site. Because of our ongoing research, and the fact that it is located on state prison property, only personnel authorized by the State Correctional Institution at Graterford are permitted on the grounds.

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COAL UNDER THE MICROSCOPE: Interpreting the Cause of Coal-Rank Change in Pennsylvania

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INTRODUCTION. A previous article by Davis (1992) dealt with aspects of coal character that were imposed at the time that plant-derived peat was laid down in swamps. The present article is concerned with the subsequent history of those bodies of peat while they were buried and subjected to the metamorphic influences of elevated temperatures and pressures over an extended period of time.

Pennsylvania is one of the world's most unique field areas in which to study the transformation undergone by coal as a result of its burial and heating within the earth's crust. Eastward across most of the state's 300-mile width, coals vary in rank from high-volatile bituminous, through medium- and low-volatile bituminous, to semianthracite and anthracite (see back cover). Geologists have studied these coals and their associated rocks in efforts to determine what geological factor or factors would have brought about such very distinct changes. This article contains a review of the substantial evolution of ideas concerning the cause of these changes in rank. Some emphasis will be placed on studies conducted at The Pennsylvania State University concerning the optical properties of coal measured under the microscope.

COAL AS A TEMPERATURE/STRESS INDICATOR. The concept of metamorphic rocks is well known. Subjected to high temperatures and pressures, limestone becomes marble, and shale becomes slate or schist. Organic matter from plants is more sensitive to temperature than most of the minerals that compose these inorganic rocks. It tends to undergo chemical transformations at lower temperatures; consequently, the sedimentary rock sequences that make up coal-bearing measures can contain a wide range of coal ranks depending on the temperatures that have been experienced. These ranks range from lignite to anthracite. Some rare lignite occurs in Pennsylvania, but economic deposits of coal are limited to the range from bituminous to anthracite.

Any characteristic of coals that varies systematically through the rank range can be used as an index of rank. Thus, the percentage yield of volatiles when a coal is heated under prescribed conditions is an index of rank, as is the carbon content and the calorific value. Volatile matter (on a dry, ash-free basis) decreases eastward from about 43 percent at the Ohio border to about 2.5 percent in the anthracite fields.

Another index of rank is the property known as reflectance. Anthracite is much brighter in appearance than bituminous coal; this feature can be quantified very precisely using a microscope equipped with a photomultiplier to measure the amount of light reflected off the surface of the brightest bands contained in the coal. These bands, typically a few millimeters thick, are composed of a material called vitrinite, a component derived mainly from the wood and bark of plants. The reflectance of vitrinites increases progressively through the rank range of coals (Figure 1) because their molecular structures become increasingly enriched in aromatic carbon structures. An advantage of reflectance as an indicator of rank compared to chemical indices, such as the amount of volatile matter or the amount of carbon, is that the latter are substantially influenced by the kinds and proportions of plant-derived materials present in a coal, and these can vary widely. Reflectance is measured only on vitrinite and so is less dependent on that kind of variability.

Several relationships have been developed between vitrinite reflectance and the temperature and time of coalification. Such relationships serve as models, which permit the calculation of temperatures in sedimentary basins over geologic time using measured reflectances and estimates of the duration of coalification.

Reflectance measurements usually vary somewhat depending upon the orientation of the specimen on which the determination is made. This is because the molecules of vitrinite, during their growth in response to the elevated temperatures experienced during burial, tend to develop a preferred orientation in response to the directed pressures to which they are subjected. Consequently, such measurements can be used to evaluate the extent of stresses imprinted upon the coal; these include stresses arising from burial and those imposed by tectonic forces.

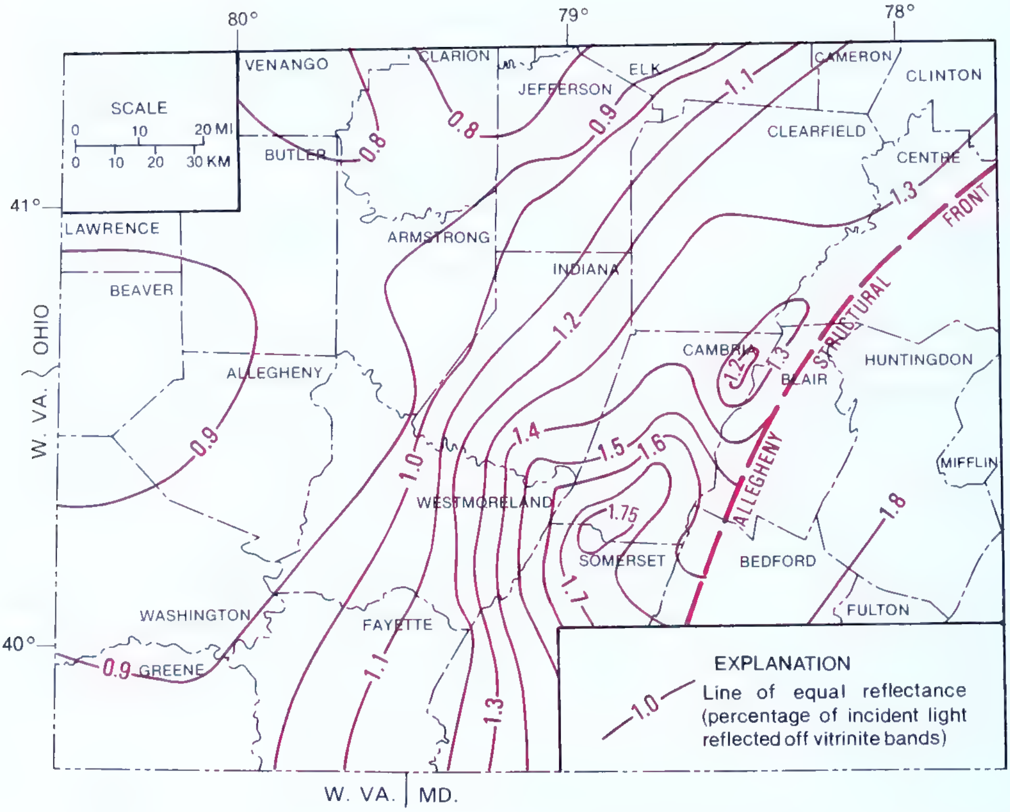

Figure 1. Isoreflectance map for the Lower Kittanning seam in western Pennsylvania (modified after Zhang and Davis, 1993).

EARLY STUDIES. David White, a geologist with the U.S. Geological Survey (USGS), made an extensive study of coalification in fields across the United States (White and Thiessen, 1913; White, 1925). In the Appalachian fields in particular, he found conspicuous evidence of an increase in rank eastward, in the direction of greatest horizontal compression as revealed by the intensity of folding and faulting. He concluded that this supported the thrust-pressure theory of coalification, although he recognized that time was also a factor, and conceded that temperatures could also have been involved. He noted that in Pennsylvania, as in other fields, metamorphism could be greater in districts where there had been no buckling or overthrusting to diminish the intensity of the stresses.

Like White, Taisia Stadnichenko (1934) recognized that variations in climate and vegetation, and the activities of biological agents, could not have been responsible for the significant variation in coal rank found in Pennsylvania. She also discounted the possible role of heat because of the apparent absence of igneous batholiths, and of depth of burial because of the lack of evidence for major eastward thickening of rocks younger than the Pennsylvanian coal measures. The field evidence, she concluded, supported White's championship of the thrust-pressure theory. The highest rank coals along the Allegheny Front occur in the Windber district; Stadnichenko noted that this region is flanked to the east by an apron or buttress of older competent rocks. This buttress would have transmitted most of the full force of the compressive thrusting westward into the coal-bearing strata. To the north and south of this district, the coal measures lie opposite areas of greater folding and thrusting, the supposed effect of which was to partially neutralize the metamorphic influence of the horizontal stresses.

J. Roberts (1924) developed a theory of anthracitization based upon his studies of coals in South Wales, including laboratory experimentation. From this, he drew an analogy with the Pennsylvania field on the basis of White's descriptions and concluded that temperature was the essential metamorphic agent. He was of the opinion that the intense folding of the rocks would have contributed to the relatively high temperatures required (in the region of 550°C, or 1022°F, according to his experiments).

The refuting of the thrust-pressure theory can be attributed substantially to the work of M. and R. Teichmüller in Europe (1966). Coal rank in the European Ruhr basin is least at its southern margin, which is where folding of the beds has been most intense. Moreover, lines of equal volatile matter, which originally would have been parallel to the earth's surface, are now parallel to the folded coal seams there. Together, these observations indicate that the present pattern of rank distribution in this basin could not have been the result of the folding pressure. As for the hypothesis that shear stress or frictional heat associated with the major thrusts in tectonically active areas could have contributed to the regional pattern of coal rank, the Teichmüllers demonstrated that these factors were influential only in the immediate vicinity of the thrust planes. Frictional heat, they pointed out, is dissipated rapidly.

As a result of broad field studies, G. H. Wood and coworkers at the USGS concluded in 1969 that the general eastward attainment of anthracitic rank in the state was due to increased burial. They recognized also that the lines of coalification were parallel to the larger and even some of the smaller structural features; they considered that this observation, and the fact that rank increased into the cores of synclines, validated White's conclusion that rank increases toward areas of greater deformation. H. Damberger (1974) of the Illinois Geological Survey, however, reached a different conclusion, noting that some of the data of Wood and his coworkers suggested that the rank trends and the coalbeds were discordant, with the younger seams in the axes of synclines having higher ranks than those on the flanks. He explained this by postulating that anthracitization had been accomplished by magmatic heating associated with the emplacement of a deep-seated intrusion during the late Paleozoic to early Mesozoic. In 1982, J. R. Levine and A. Davis offered yet another explanation for the high ranks found in the cores of synclines. They attributed the phenomenon to a purely structural cause, citing evidence for significant uplift of the coal-bearing rocks by high-angle reverse faulting in the centers of the basins.

RECENT STUDIES EMPLOYING OPTICAL PROPERTIES. With burial and tectonic pressures out of consideration as causes of coalification, the emphasis in Pennsylvania has shifted to clarification of whether the lateral variations in temperature necessary to create the observed distribution of rank were achieved through differential burial or heat flow.

In 1981, J. C. Hower and A. Davis employed the change in coal rank with depth in one of the coalification models referred to above. In this way, they were able to estimate the differences in coalification temperature across the stratigraphic intervals represented by vertically separated coal horizons. They calculated that the paleogeothermal gradient in Westmoreland County, close to the Ohio border, was about 33°C/km (96°F/mi), whereas that in Somerset County, close to the Allegheny Front (see back cover), had been about 40°C/km (116°F/mi). Their estimate of depth of burial across the area was about 3.5 to 4 km (2.2 to 2.5 mi). Their evidence suggested that the depth of burial was more or less uniform across the area.

In 1986, J. R. Levine argued the case for normal paleogeothermal gradients across the state and for depths of burial as much as 6 to 9 km (3.7 to 5.6 mi) in the Anthracite region. He estimated geothermal gradients in two Southern Anthracite field boreholes in a manner similar to that used by Hower and Davis; the values he determined (about 33°C/km, or 96°F/mi) are similar to those reported above for the Allegheny Plateau. In support of his conclusion, Levine cited a study of the trend of sandstone porosities across the North-Central and Northern Anthracite coalfields by S. T. Paxton (1983); the results of this study suggested that overburden thickness could have been as much as 9 km (5.6 mi) in the Anthracite region and 3 to 6 km (1.9 to 3.7 mi) in the medium-volatile-bituminous Blossburg basin. Levine proposed that the abnormally high overburden thicknesses were due to an unusual amount of crustal downwarp; some of the overburden could have been emplaced tectonically in the form of overthrust sheets.

Recently, E. Zhang and A. Davis (1993) applied a coalification model to reflectance data measured for eight boreholes drilled by the Pennsylvania Geological Survey through the coal measures in western Pennsylvania. Their approach required reconstructing the burial and uplift histories of the coal-bearing rocks across the area to the west of the Allegheny Front. They concluded that maximum burial depth had increased from 3 to 5 km (1.9 to 3.1 mi) and that the geothermal gradient had increased from 26 to more than 33°C/km (75 to more than 96°F/mi) eastward across the study area. Already the basis of Paxton's conclusion of a massive eastward increase in burial had been called into question; the loss of sandstone porosity that he observed could have been brought about by mineralogical change in addition to physical compaction.

In explaining the increasing geothermal gradient across western Pennsylvania, Hower and Davis (1981) had suggested that heat flow did not vary progressively across the area but that there were structurally defined heat-flow provinces; within provinces, heat flow would have been more or less uniform, but the major changes in coal rank coincide with zones overlapping the province boundaries. One of the coalification regimes delineated by Zhang and Davis (1993) is centered around northern Somerset County and has an unusual concentric pattern of coalification (Figure 1). These authors postulated that the high heat flow and paleogeothermal gradients suggested by the model for this regime could have been derived in part from hot fluids originating from an eastern source and channeled upward along fractures and faults concentrated in the area. Based upon mineralogical evidence, E. J. Daniels and coworkers (1990) had already concluded that the rate of anthracitization in eastern Pennsylvania could have been accelerated by heat from upwelling fluids. The driving force for these hydrothermal fluids was Alleghanian uplift on the eastern flank of the basin.

If Zhang and Davis are correct, both depth of burial and increasing paleogeothermal gradient were responsible for the eastward increase in rank in the western part of the state. However, a conclusive explanation for the coal-rank pattern and the origin of the anthracites in Pennsylvania remains elusive.

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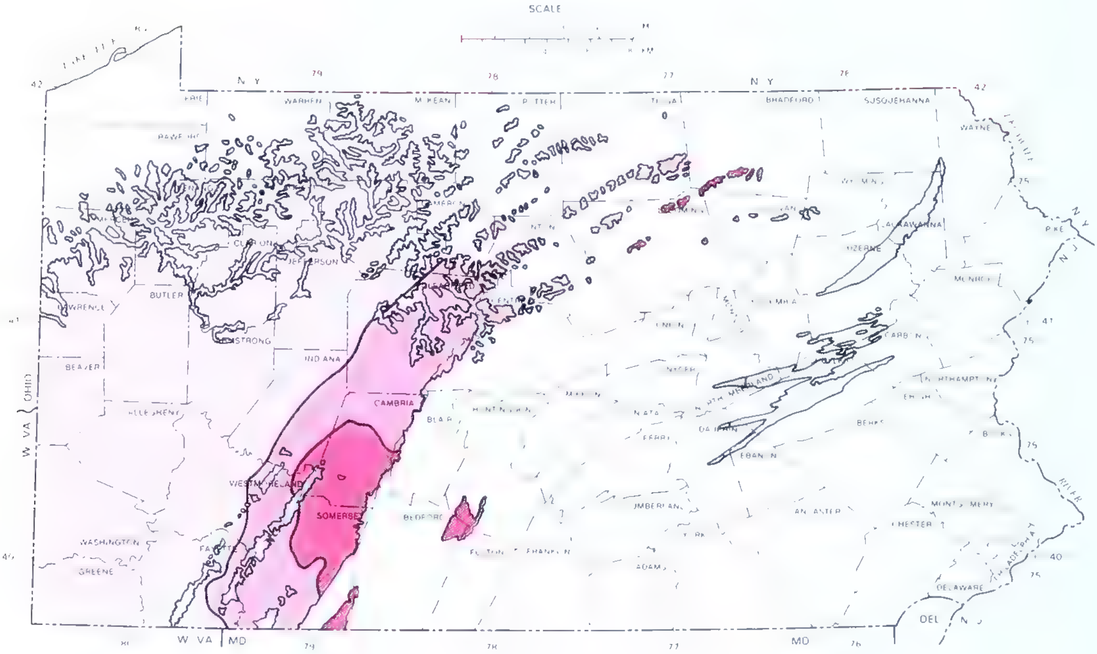
COAL DISTRIBUTION AND RANKS IN PENNSYLVANIA

(See article on page10)



EXPLANATION

BITUMINOUS FIELDS		ANTHRACITE FIELDS	
☐	High-volatile bituminous coal	☐	Anthracite
▨	Medium-volatile bituminous coal	▨	Semi-anthracite
■	Low-volatile bituminous coal		

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